

DEVELOPMENTS AND PLANS FOR THE NEXT e^+e^- LINEAR COLLIDER

P.N. Burrows

University of Oxford

CTEQ/IPPP Summer School

June 23 2001

- Introduction
- Physics motivation
- Overview of design issues
- World test facilities
- UK contributions
- Sociology politics + finance
- Outlook + prospects

Popular myth:

"Hadron colliders: discovery machines"
Electron colliders: exploitation machines"

FALSE!

- Major discoveries made at both e^+e^- and hadron colliders

- e^+e^- : ψ , $\Upsilon^\pm$, jets, gluon...

- Precise meas. made at hadron colliders

- TeVatron: M_W , B physics...

LHC: SUGRA simulations

Remember:

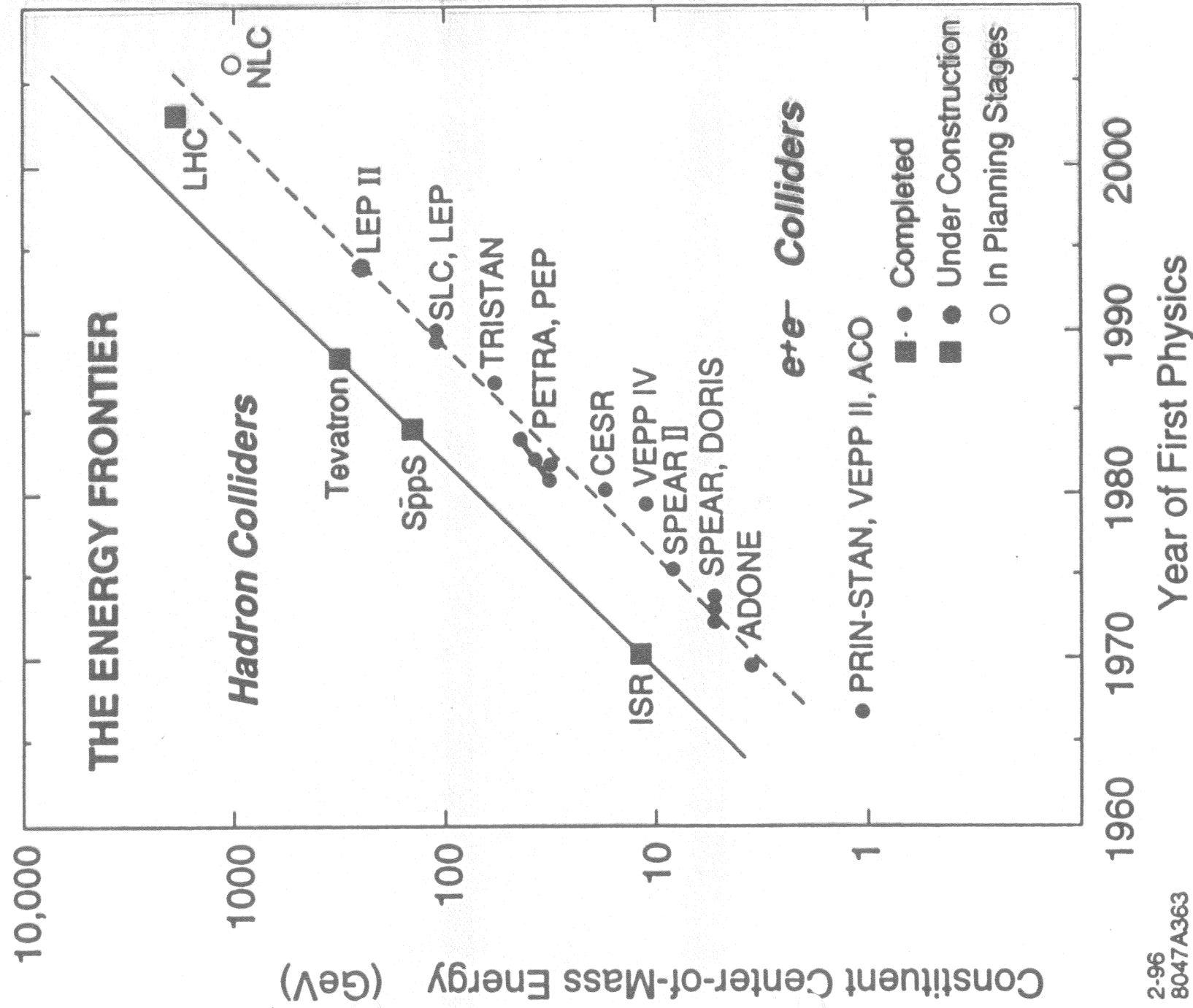
- Force-carrier of strong interactions

(g) discovered at e^+e^- collider (PETRA)

- Force-carriers of weak interaction

($W^\pm, Z^0$) discovered at hadron collider (SPPS)

30 years of e^+e^- and hadron colliders
working in parallel



INTERNATIONAL LC WORKSHOPS

PHYSICS/DETECTOR WORKSHOPS

Saariselka	Sept. 1991
Hawaii	April 1993
Morioka	Sept. 1995
Sitges	April 1999
Fermilab	October 2000
Korea or Japan	May 2002

ACCELERATOR WORKSHOPS

SLAC	1988
KEK	1990
Protvino	1991
Garmisch	1992
SLAC	1993
KEK	1995
Moscow	1997
Frascati	1999

LINEAR e^+e^- COLLIDERS:
PHYSICS AND DETECTORS

- Regional working groups:

Europe (ECFA/DESY)

(Miller)

North America

(Baltay)

Asia (ACFA)

(Komamiya)

- Common structure of working groups

- Agreed inter-regional coordination

- Next international workshop:

Fermilab, October 22-28 2000

2nd Joint ECFA/DESY Study on Physics and Detectors for a Linear Electron-Positron Collider.

Working Groups

(See the groups' own webpages - as they develop - for more details of membership and plans).

● Physics; theory and experimental analysis.

1. Top quark physics

- Theory conveners: Johann Kuehn, Werner Bernreuther
- Experimental conveners: Manel Martinez, Ramon Miquel

2. Electroweak Gauge Theories

- Theory conveners: Thorsten Ohl, George Gounaris
- Experimental convener: Klaus Moenig

3. SUSY

- Theory conveners: Alfred Bartl, Walter Majerotto, Ulrich Ellwanger
- Experimental conveners: Yves Sirois, Uli Martyn, Graham Blair

4. QCD

- Theory conveners: Arndt Brandenburg, Michael Krämer, Matteo Cacciari
- Experimental conveners: Phil Burrows, Albert de Roeck

5. Higgs

- Theory conveners: Abdelhak Djouadi, Berndt Knichl
- Experimental conveners: Eilam Gross, , Sijbrand de Jong, Alex Read

6. Alternative Theories

- Theory convener: Reinhold Rueckl, Michael Spira
- Experimental convener: Graham Wilson

● Tools

1. Generators and standard processes.

- Theory conveners: Mike Seymour, Stanislaw Jadach
- Experimental convener: Hywel Phillips

2. Detector simulation.

- Conveners: Martin Pohl, Graham Blair

● Detector Performance and R&D.

- Conveners: Ron Settles, Chris Damerell, Patrick le Du, Sergio Bertolucci, Marcello Piccolo

● Machine-Detector Interface.

- Conveners: Martin Leenen, Olivier Napoly, Nick Walker, Jon Butterworth

ACFA Joint Linear Collider Physics and Detector Working Group

[What's New](#) | [Events](#) | [Mailing List](#) | [Institutions](#) | [Members](#) | [Subgroups](#)

[The 1st ACFA Workshop on Physics/Detector at the Linear Collider](#)

Physics

[Higgs](#)
[SUSY](#)
[New Particles](#)
[Top](#)
[QCD, Two Photon](#)
[Electroweak](#)

The Asian Committee for Future Accelerators (ACFA), considering the importance of the Electron-Positron Linear Collider Project and the potential of the Asian community to realize it, has initiated the Physics & Detector Study Group under ACFA.

The charge of the group is to elucidate physics scenario and experimental feasibilities at the Linear Collider. Taking account of the scale of and the world-wide interests in such project, actual studies shall be open for other regions and hopefully carried out in a more global scope.

Detectors

[Vertex Detectors](#)
[Central Tracker](#)
[Particle Identification](#)
[Calorimeter](#)
[Muon Detector](#)
[Data Acquisition/Electronics](#)

What's New

[News about this web pages](#)
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Working Group

[About the working group](#)
[Contact persons](#)

Interface

[Interaction Region](#)
[Luminosity Monitor](#)
[Polarization](#)

Members

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Computing/Network

[Physics Tools](#)
[Simulator](#)
[Analysis Framework](#)
[W3](#)

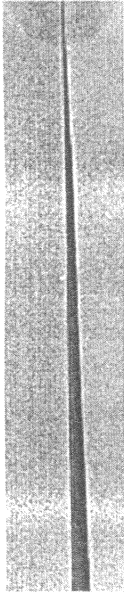
Related Link

[Electron-Positron Linear Collider Project](#)

Options

[Electron-electron](#)
[Electron-gamma](#)
[Gamma-gamma](#)

N. America



e^+e^- , electron-photon, photon-photon int

- Karl van Bibber (vanbibber1@llnl.gov)
- Clem Heusch (heusch@slac.stanford.edu)
- Leslie Rosenberg (ljr@mitlms.mit.edu)

Working Groups

The conference will have the working groups listed working groups are also shown). Some of these will see here.

Interaction region, backgrounds

- Thomas Markiewicz (twmark@SLAC.Stanford.EDU)
- Stan Hertzbach (hertzbac@slac.stanford.edu)

Detector and Physics Simulation

- Tim Barklow (timb@slac.stanford.edu)
- Richard Dubois (richard@slac.stanford.edu)
- Michael Peskin (mpeskin@slac.stanford.edu)

Vertex Detectors

- Jim Brau (jimbrau@quest.uoregon.edu)
- Harry Nelson

Tracking

- Keith Riles (kriles@umich.edu)
- Dean Karlen (karlen@physics.carleton.ca)
- Chris Hearty

Particle ID

- Hitoshi Yamamoto (hitoshi@uhhep.phys.hawaii.edu)
- Richard Stroynowski

Calorimetry

- Frank Porter (fcp@cithex.caltech.edu)
- Ray Frey (rayfrey@bovine.uoregon.edu)

Muon Detector

- Dave Koltick (Koltick@physics.purdue.edu)
- Jack Ritchie (ritchie@hep.utexas.edu)

Data Acquisition / Electronics

- Tony Barker (tonyb@cuhep.Colorado.edu)
- Bob Jacobsen

Electroweak and Strong Gauge

- Tim Barklow (timb@slac.stanford.edu)
- Mike Peskin (mpeskin@slac.stanford.edu)

Higgs

- Rick Van Kooten (Rick.Van.Kooten@cern.ch)
- Bill Marciano (marciano@bnlarm.bnl.gov)

SUSY

- Teruki Kamon (kamon@fnal.gov)
- Bob Hollebeek (bobh@hollebeek.hep.upenn.edu)
- Hitoshi Murayama (murayama@lbl.gov)
- Uriel Nauenberg (uriel@cuhep.colorado.edu)

New Phenomena

- Slawek Tkaczyk (tkacz@fnal.gov)
- JoAnne Hewett (hewett@slac.stanford.edu)

Top Physics

- David Cinabro (cinabro@physics.wayne.edu)
- David Gerdes (gerdes@umaxpl.physics.lsa.umich.edu)
- Andreas Kronfeld (ask@fnal.gov)

QCD, Two Photon Physics

- Bruce Schumm (schumm@scipp.ucsc.edu)
- Lance Dixon (lance@slac.stanford.edu)

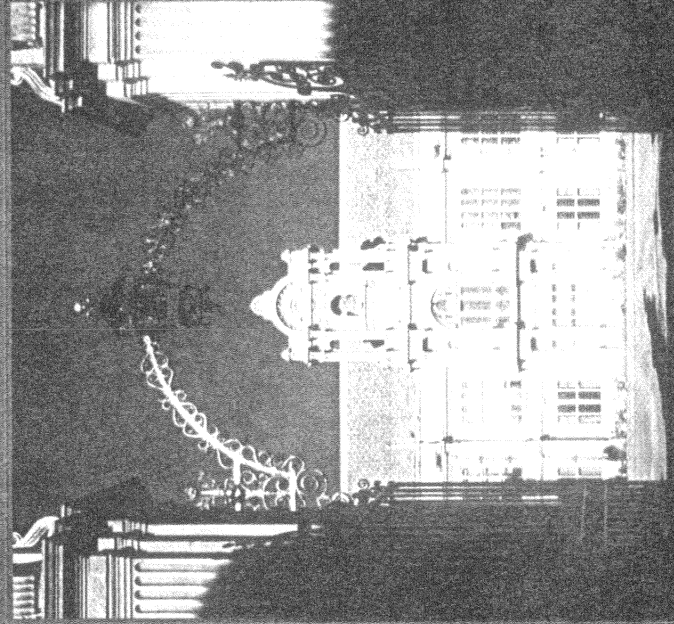
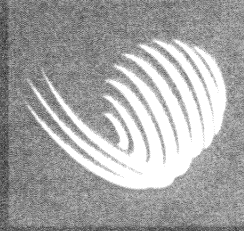
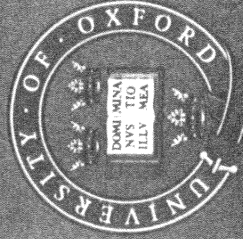
Physics and Detectors for a

Linear Electron-Positron Collider

2nd Joint ECFA / DESY Study

4th Workshop : Oxford University, 20 - 23 March 1999



PPARC

•SUSY

•QCD

•Higgs

•Generators

•Simulations

Participants invited to : the full workshop, or, final summary talks
March 22+23

- Top quark physics
- Detector performance
- Alternative theories
- Electroweak gauge theories
- Machine-detector interface

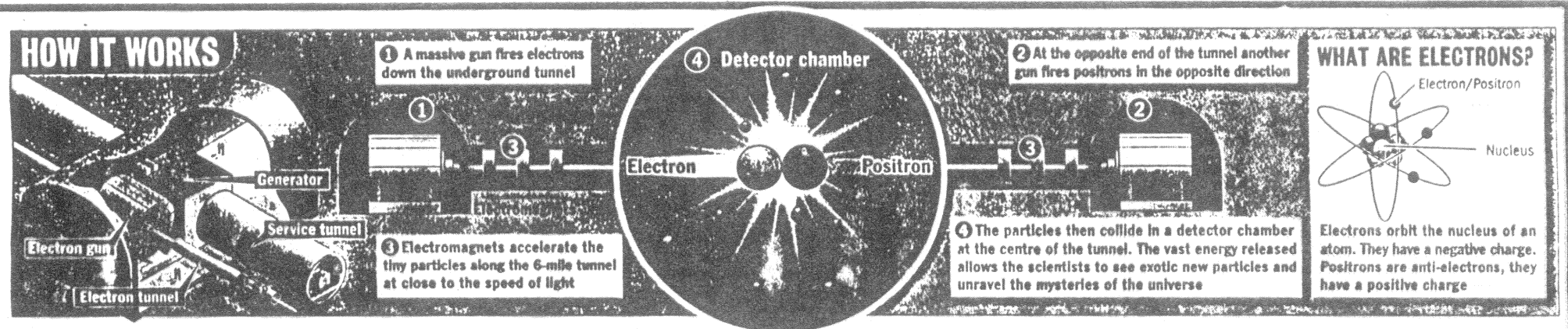
Local organising committee :

P.N. Burrows (p.burrows@physics.ox.ac.uk)
C.J.S. Damerell (c.damerell@rl.ac.uk)
G. Myatt (g.myatt@physics.ox.ac.uk)

(ECFA / DESY Organising committee)

M. Danilov - Moscow D. J. Miller - UCL (chair)
E. Fernandez - Barcelona F. Richard - Orsay
R-D. Heuer - Hamburg T. Sjöstrand - Lund
L. Jönsson - Lund R. Settles - Munich
P. Laurelli - Frascati A. Wagner - DESY
M. Leenen - Desy P.M. Zerwas - DESY

www.desy.de/conferences/ecfa-desy-lc98.html



Gunning for the big bang

BY MICHAEL HAMMON
SCIENCE CORRESPONDENT

SCIENTISTS hope to recreate the birth of the universe by firing two six-mile-long guns to produce a mini big bang.

Next week the world's top physicists meet in Oxford to plan the £1billion project, including building the megaguns – the biggest ever seen.

They plan to point them at each other deep underground. When they are fired, their "bullets" will collide at virtually the speed of light.

The explosion of energy will provide a snapshot of what happened just one-trillionth of a second after the universe was created. Physicists use these guns, or linear

Race to build £1billion weapons that could unveil the mysteries of creation

accelerators, to smash atoms and sub-atomic particles into each other at high speed and the resulting debris often contains exotic new particles, including anti-matter.

The goal is to get the particles moving as fast as possible, using powerful electrical fields to catapult them down a tube.

Until now the world's fastest accelerators have been circular but speed is lost because the beams use energy as they charge and the

bends. The biggest is a 27-kilometre ring in Switzerland operated by Cern, the European nuclear research centre.

The straight accelerators being planned now would allow much higher speeds and the electrons and anti-electrons – sub-atomic particles that carry electrical charge – will collide at more than 99 per cent of the speed of light.

The scientists are aiming to create 1,000 billion volts of energy and

the technology needed for this will challenge some of the world's greatest minds.

Three rival schemes are being pursued in Europe, Japan and the US, and whichever is chosen, the likely spin-off for Britain would be to supply advanced components.

Dr Christine Sutton, an Oxford physicist working on the big bang project said: "This will help us to understand where we came from.

"By going higher and higher

energies, you are effectively going back in time – recreating a big bang. This accelerator will produce five times or more the energy at Cern."

Getting two beams of electrons a fraction of a millimetre wide to hit each other head-on over a distance of 12 miles has been likened to two machine-gunners firing at each other so precisely that all the bullets collide in mid-air.

"It'll take some damn good engineering," Dr Sutton said.

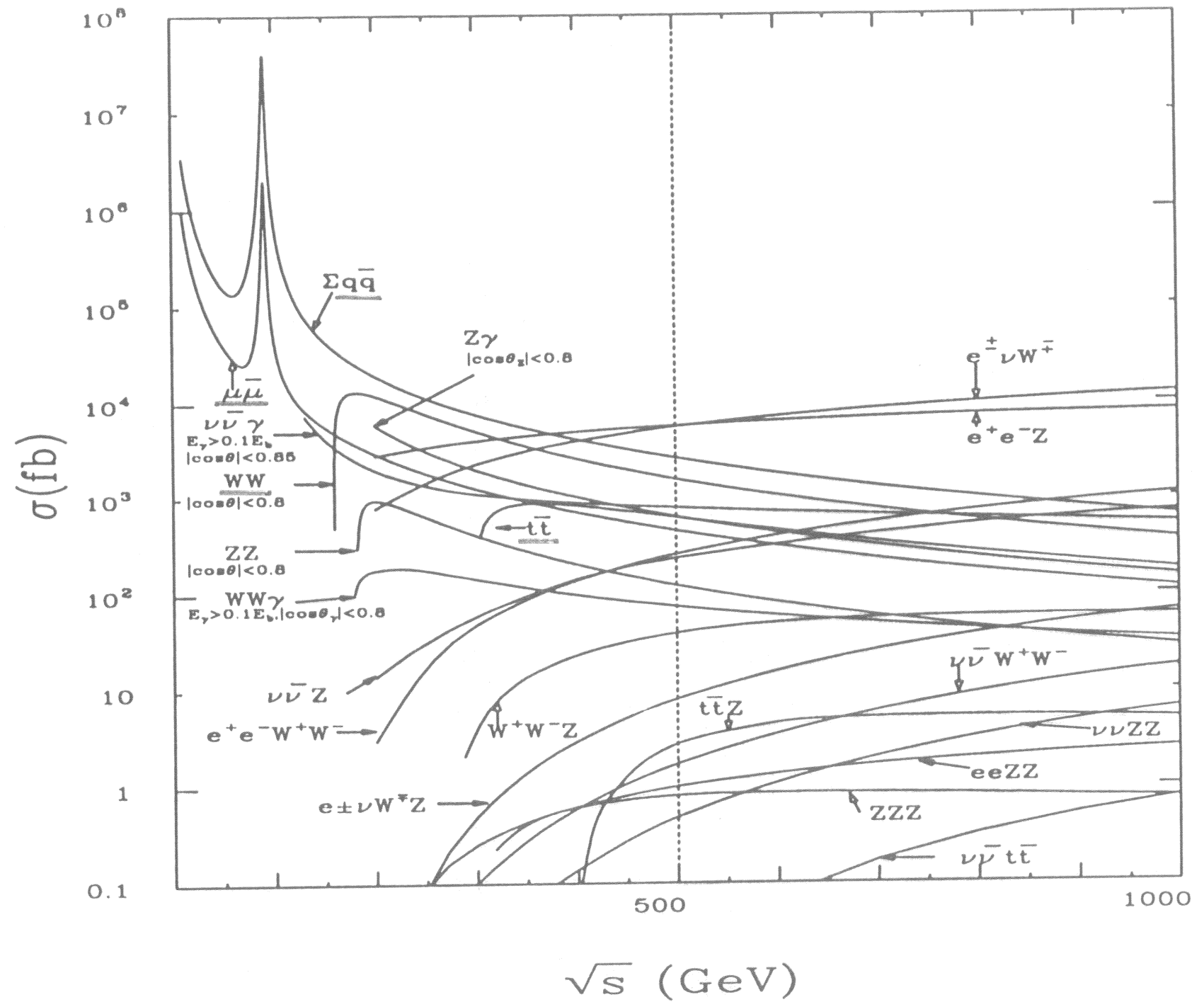
Some physicists have speculated that super-powerful accelerators could produce black holes, or even mini universes, by mistake.

But Dr Sutton said: "I don't think there's much chance of creating a universe – that would require a much bigger machine."

THE COMPLEMENTARITY OF e^+e^-

- Clean experimental environment
- Background processes well calculated + measured:
 $\Rightarrow$ signal/background $\geq 1/100$
- Ability to scan systematically in c.m. energy
 $\Rightarrow$ disentangle new-particle thresholds
- Polarised e^- (and maybe e^+)
 $\Rightarrow$ unravel spin structure of new dynamics
- Incisive measurements via jet/flavour tagging
eg. $H^0 \rightarrow b\bar{b}, c\bar{c}, \tau^+\tau^-$ ($t\bar{t}, W^+W^-, Z^0Z^0$)
 $\Rightarrow$ pin down fundamental dynamics
i.e. is it the SM, MSSM, SUGRA, ... Higgs?!
- Possibility for $\gamma\gamma, e^-e^-, e\gamma$ colliders

S.M. Cross sections



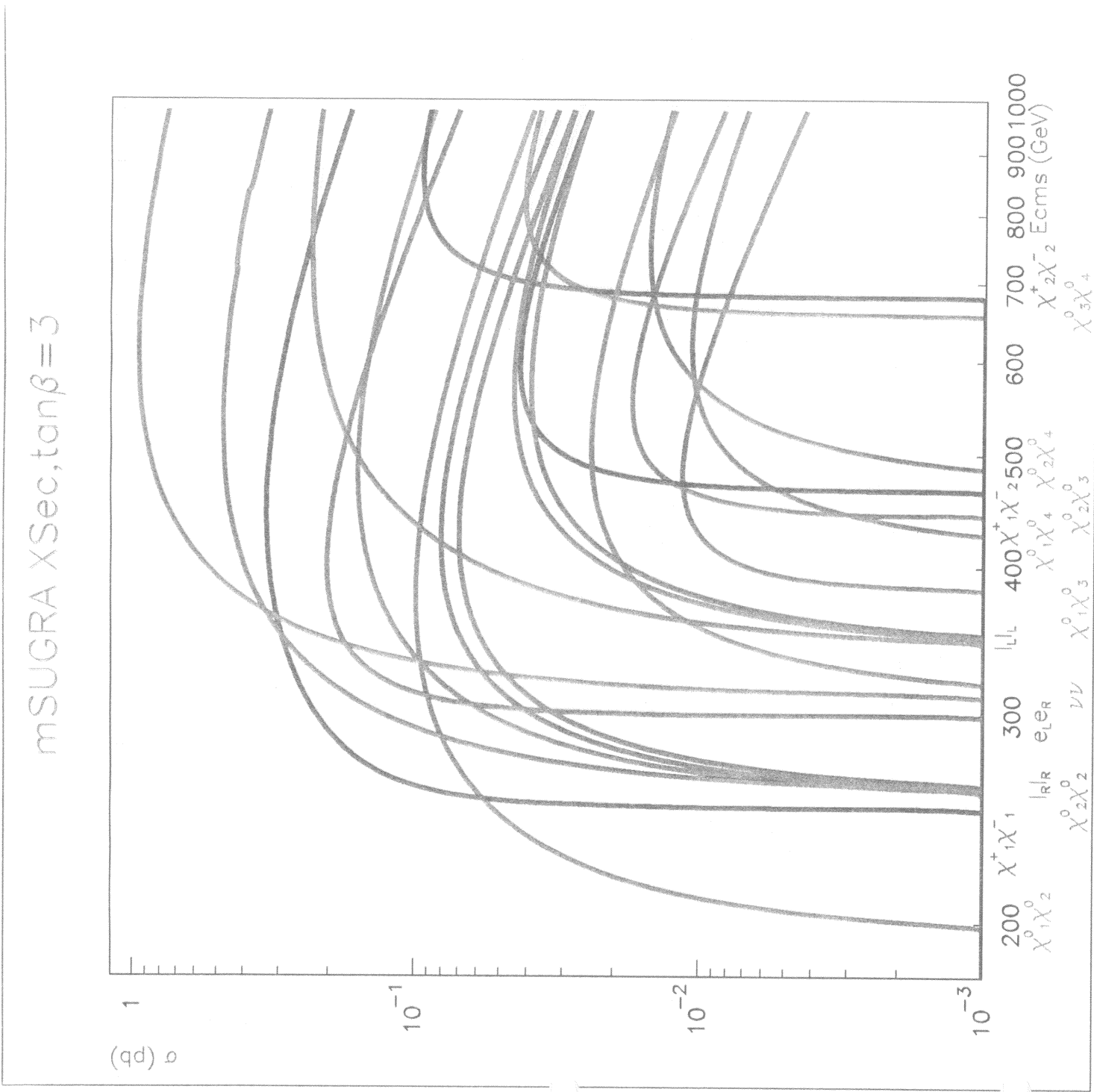


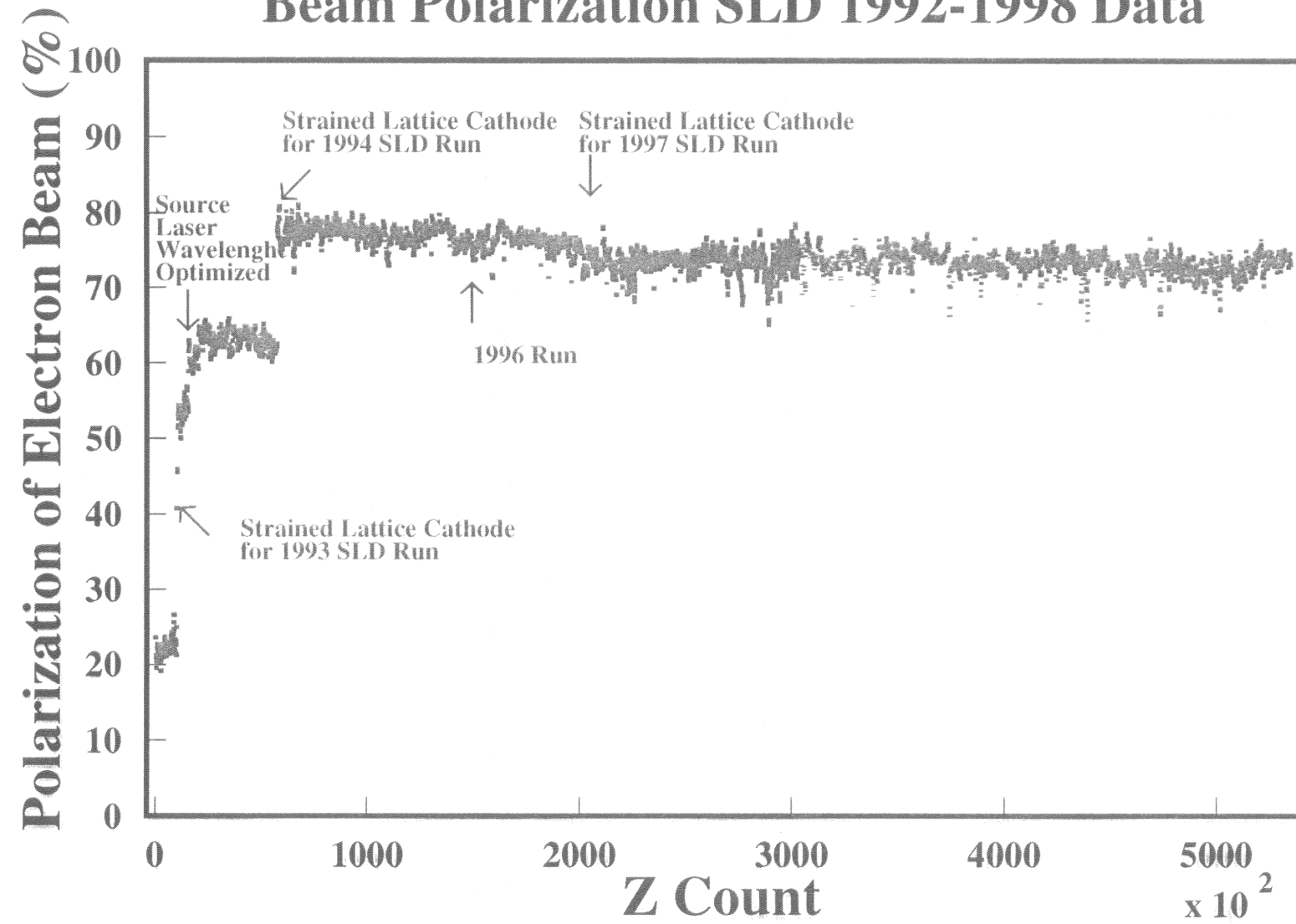
Figure 1: Cross sections for SUSY production for the mSUGRA point

$m_0 = 100\text{GeV}$ $M_{1/2} = 200\text{GeV}$ $A = 0\text{GeV}$ $\text{sign}(\mu) = +$

RGE performed using separate theoretical algorithms supplied by S Ambrosanio and W Porod, which use 2-loop RGEs for gauge couplings, gaugino masses and 3rd generation Yukawas and one loop for the other soft masses and couplings. The theoretical algorithms were interfaced to SUSYGEN and PYTHIA to obtain physical masses and cross sections.

G A Blair

Beam Polarization SLD 1992-1998 Data

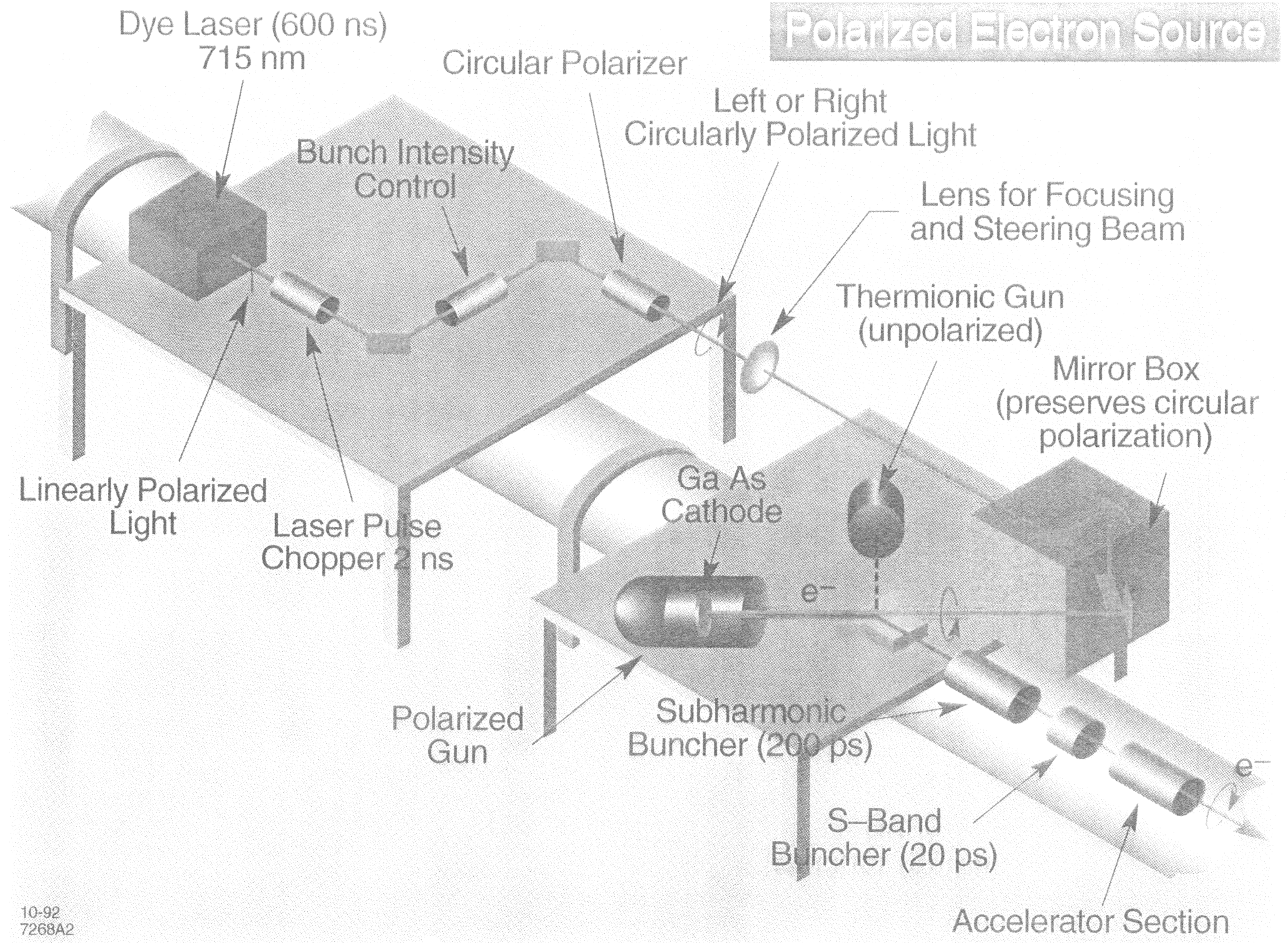


Electron - Beam Polarisation

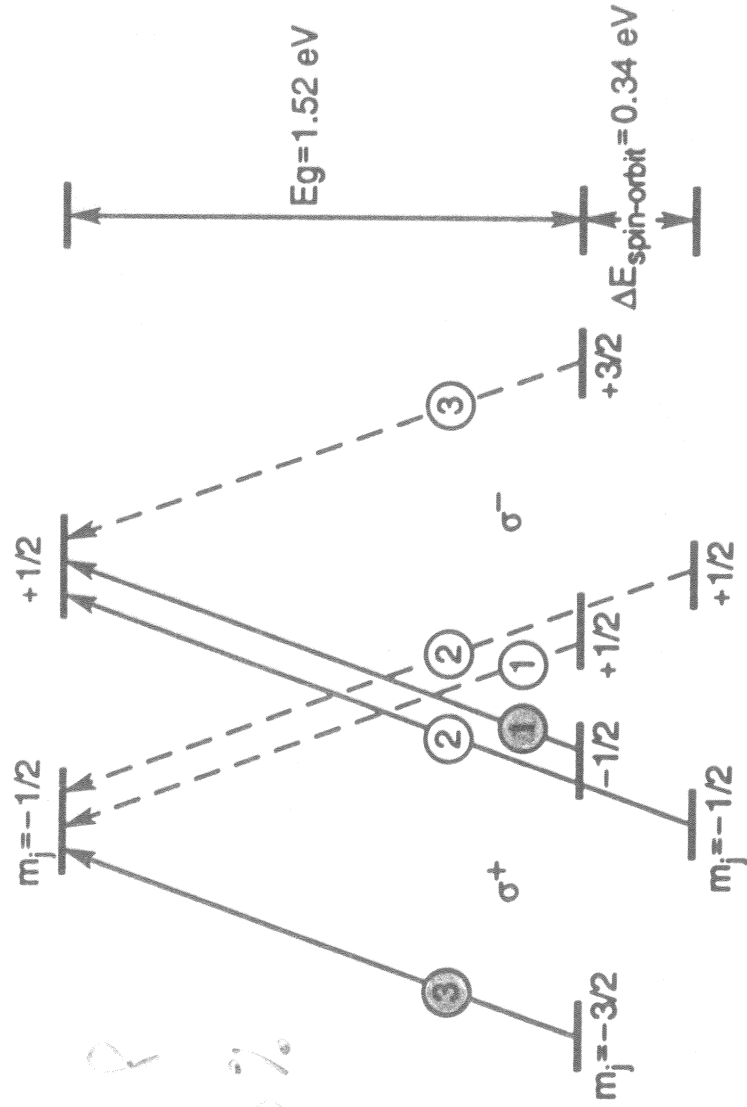
- $|P| \sim 78\%$ achieved routinely at SLC
using "strained lattice" GaAs(P) cathodes
- R+D ongoing at SLAC + in Japan
 $|P| \sim 90\%$ may be possible

- $\frac{\Delta P}{P} \sim 0.7\%$ at SLD now
 $\Rightarrow 0.5\%$ ultimately

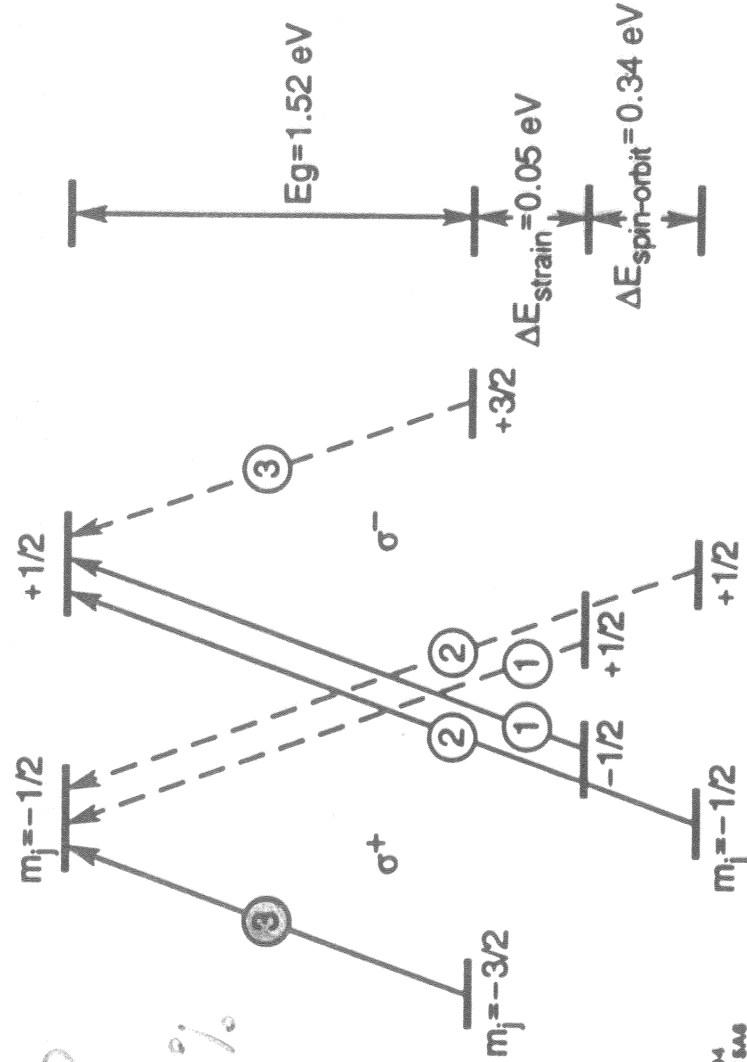
Polarized Electron Source



GaAs Energy Levels

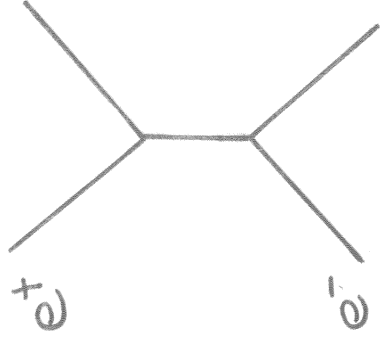
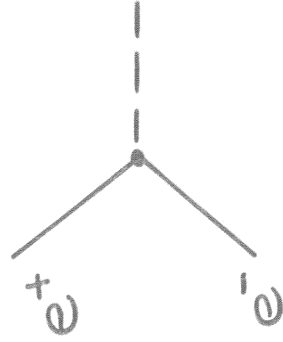


Strained Induced Splitting
 Strain Axis Parallel to Incident Photon Axis



With highly-polarised electrons,
manipulating sign of P probes:

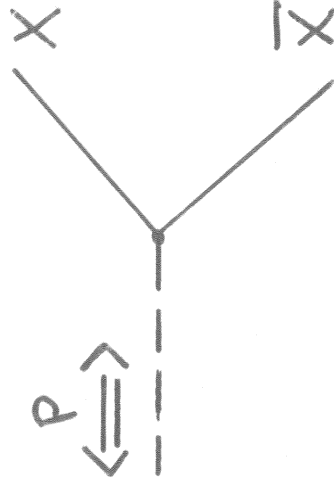
- helicity structure of init. state coupling:



eg. A_{LR} at SLD, W^+W^- at LC

$\Rightarrow$ info from cross-sections $\oplus$ asymmetries

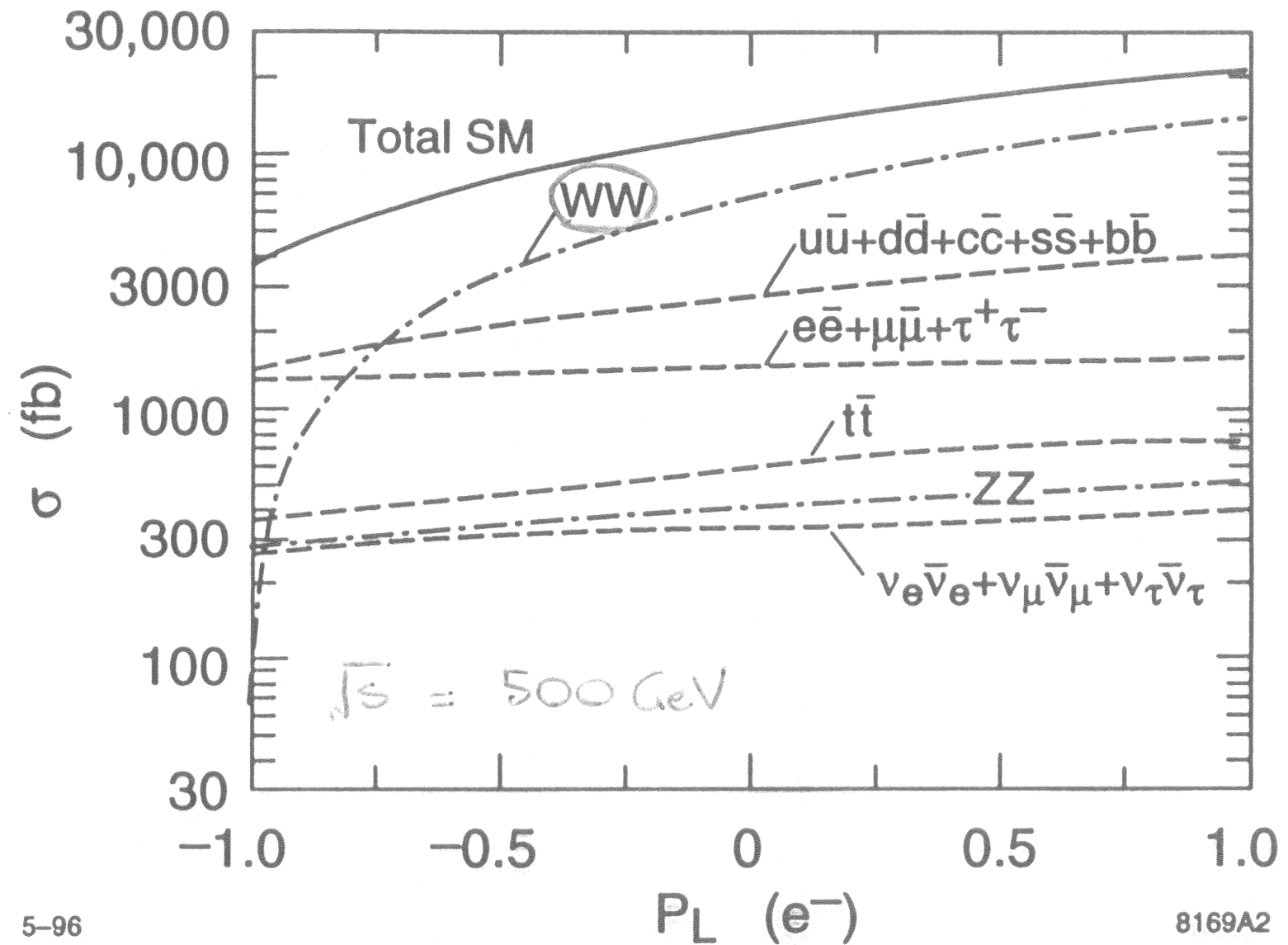
- helicity structure of final-state coupling:



eg. $\tilde{A}_{FB}$ at SLD

$\Rightarrow$ info from angular distns. $\oplus$ asymmetries

Beam polarisation essential tool
for unravelling helicity structure of
the dynamics

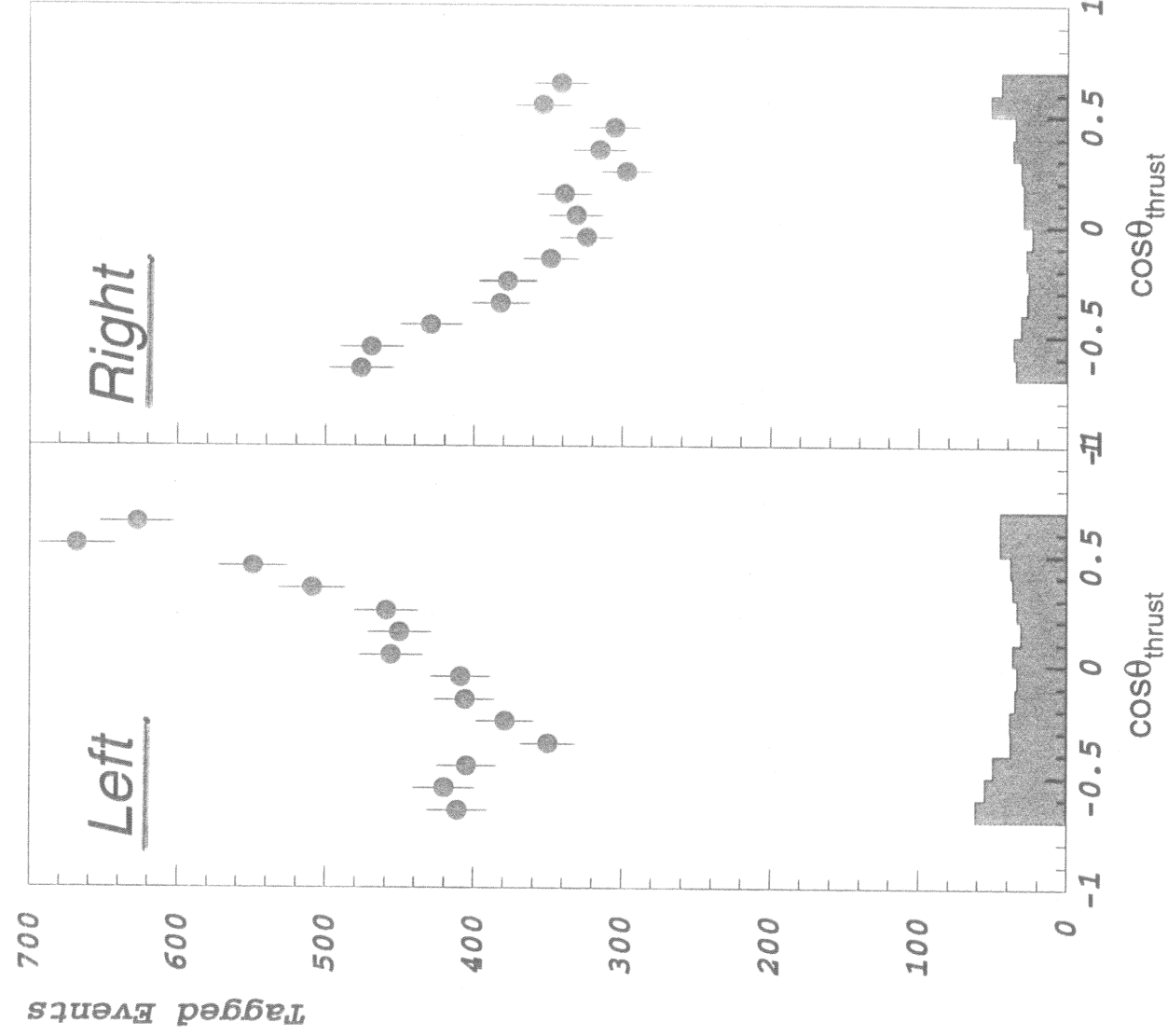


Right.

Left.

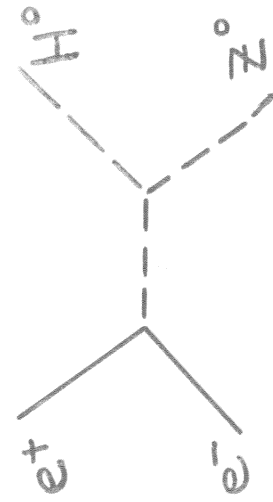
b-quark polar angle

A_b from Jet-Charge, SLD 1993-1995



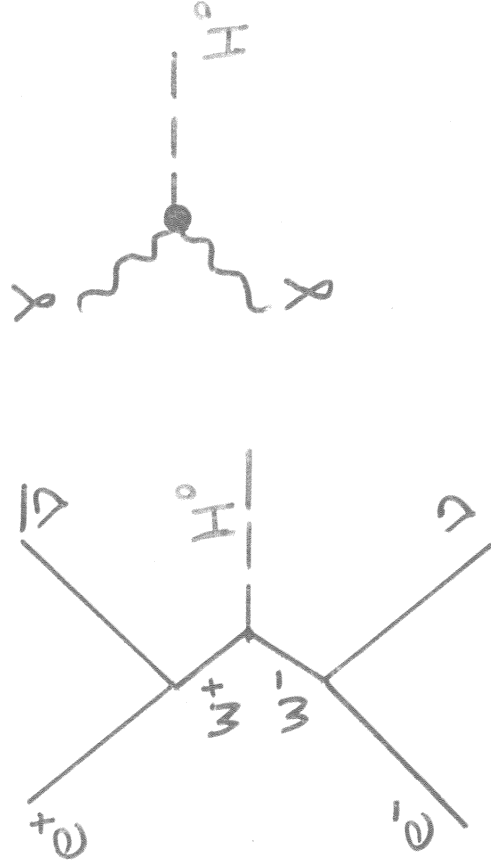
The High Energy e^+e^- Programme

Higgs

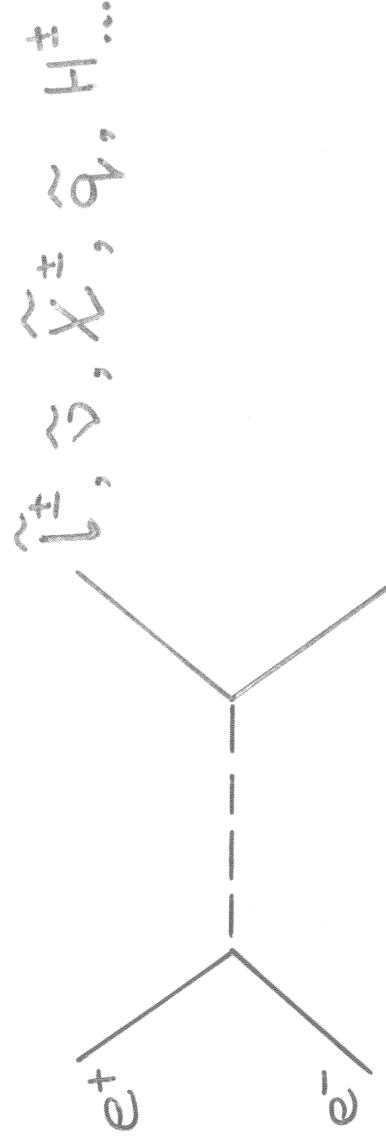


$H^0 \rightarrow b\bar{b}, c\bar{c}, \tau^+\tau^- \dots$

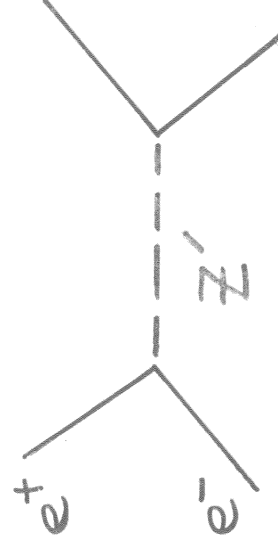
$(H^0 \rightarrow W^+W^-, t\bar{t} \dots)$



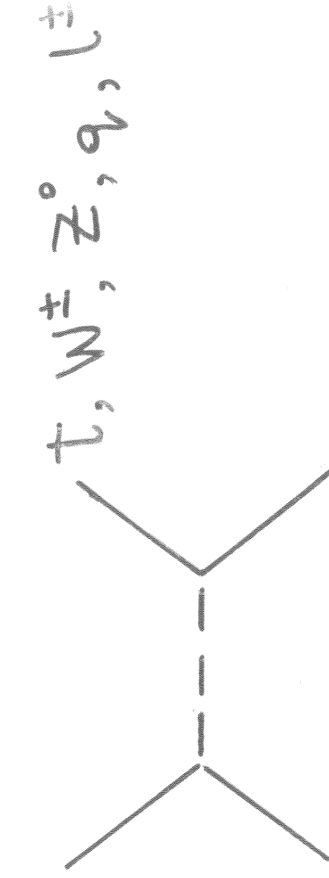
SUSY...



New gauge bosons



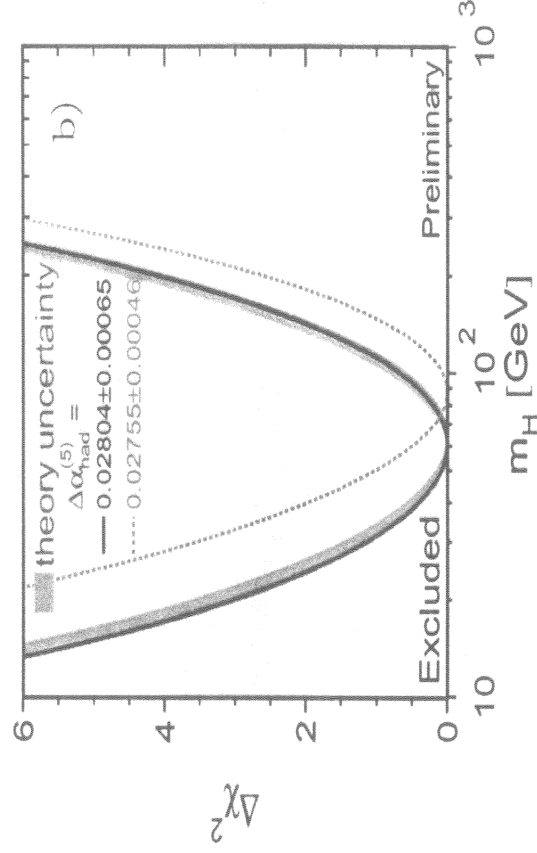
Standard physics



CURRENT SITUATION

- No Higgs boson or non-Standard Model particle observed
(Hint at LEP: $M_H \simeq 115 \text{ GeV}$ (2.9σ))

- Strong constraints:



$$114 \leq M_H \leq 206 \text{ GeV} \quad (95\% \text{ c.l.})$$

(NB: all known SUSY models require $M_H \leq 200 \text{ GeV}$)

- A Higgs boson (and possibly SUSY particles) likely to be discovered at Tevatron or/and LHC
- An e^+e^- collider required to measure Higgs: intrinsic spin - is it a scalar?
quantum numbers - is it CP-even?
couplings to gauge bosons + fermions, esp. to b, c, τ
- UK PPESP: 'highest priority beyond LHC'

Standard Model. Higgs

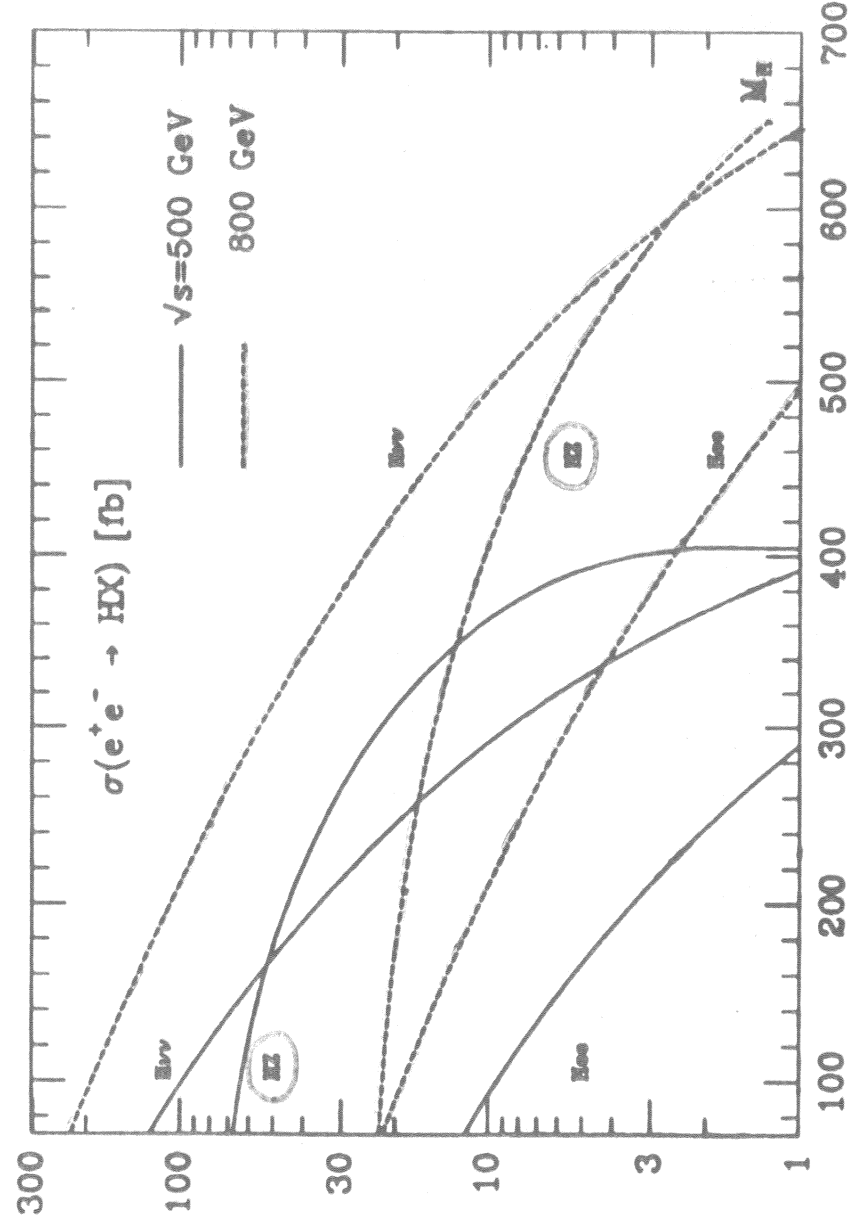
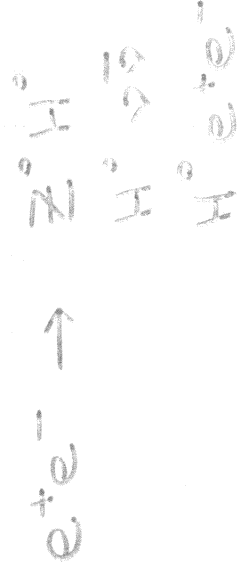
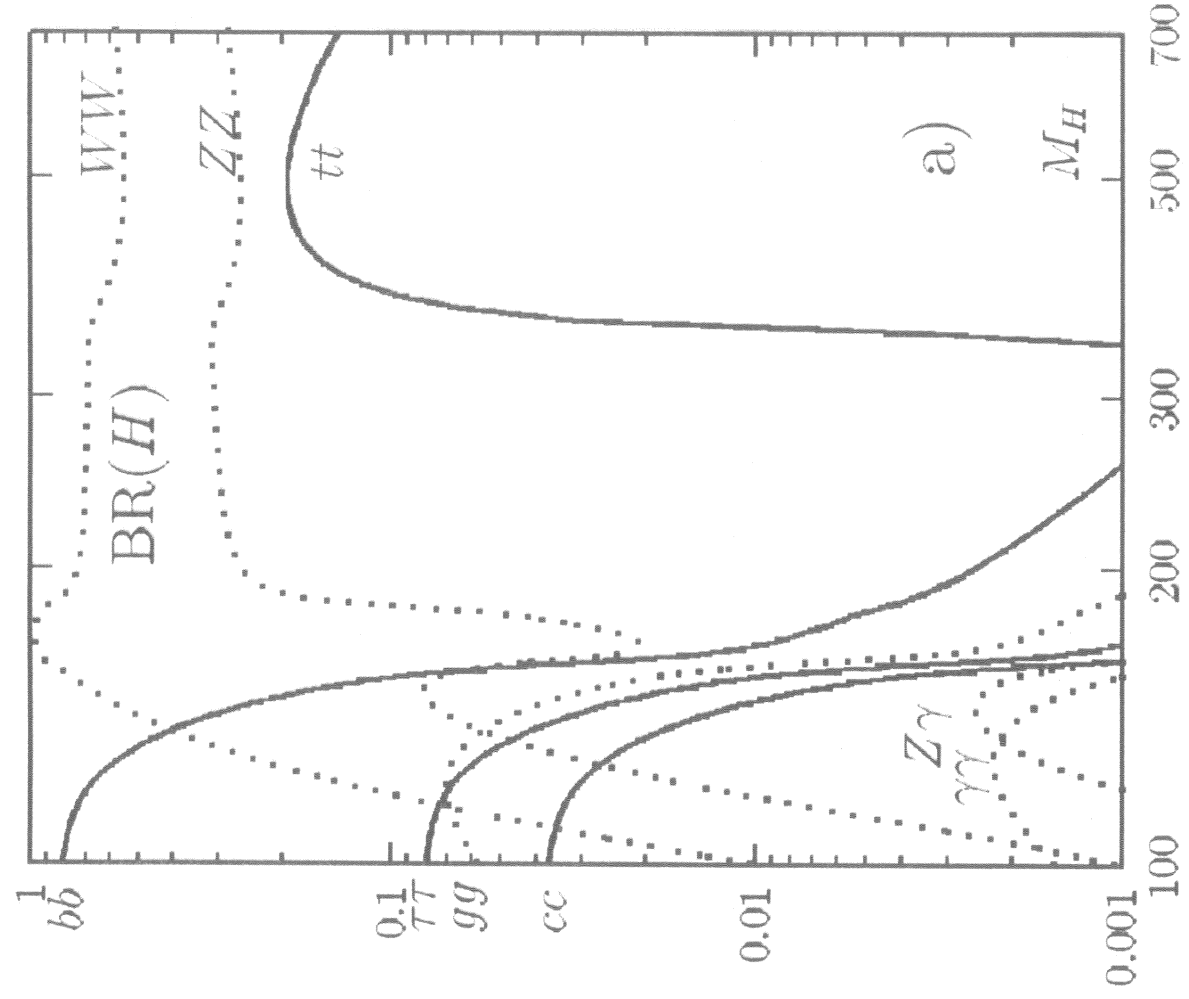


Figure 1.22: The cross section for the production of SM Higgs bosons in Higgs-strahlung $e^+e^- \rightarrow ZH$ and WW/ZZ fusion $e^+e^- \rightarrow \bar{\nu}\nu/e^+e^-H$; solid curves: $\sqrt{s} = 500$ GeV, dashed curves: $\sqrt{s} = 800$ GeV.



Some Numbers

$$\sqrt{s} = 500 \text{ GeV}$$

$$\mathcal{L} = 2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \quad (= \text{SLAC/KEK, } \frac{2}{3} \times \text{DES-Y})$$

$$\int dt = 10^7 \text{ s} \quad (1 \text{ design year})$$

Process	$\sigma \text{ (fb)}$	# evs / year *
$Z^0 H^0 \text{ (200 GeV)}$	~ 50	20,000
$t\bar{t}$	~ 500	200,000
$W^+ W^-$	$\sim 5,000$	2,000,000
$Z^0 Z^0$	~ 300	120,000
$q\bar{q}$	$\sim 3,000$	1,200,000

* radiative corrections $\times \frac{1}{3}$
+ beamstrahlung

Precision Higgs Physics

($120 < M_H < 160 \text{ GeV}$, 500 fb^{-1})

1. Mass: $\Delta M_H \sim 50 \text{ MeV}$

2. Cross-section: $\Delta \sigma_{\text{ZH}} / \sigma_{\text{ZH}} \sim 2\%$

3. Couplings to fermions:

$f \quad \frac{\Delta \text{BR}}{\text{BR}} (H^0 \rightarrow f\bar{f})$

$b \quad 2\%$

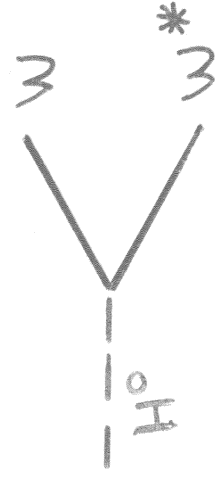
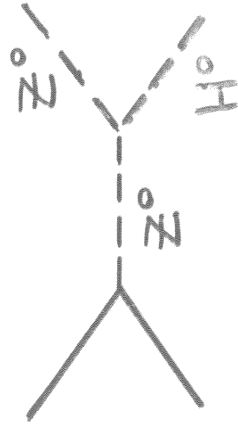
$c \quad 8\%$

$\tau \quad 6\%$



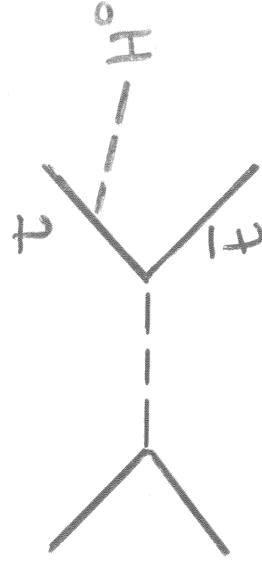
4. Gauge couplings:

$\frac{\Delta g}{g} \sim 5\%$



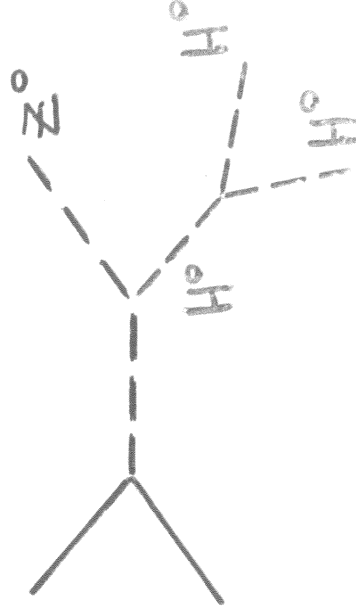
5. Top Yukawa coupling:

$\Delta g_{\text{tth}} / g_{\text{tth}} \sim 5\%$
(200 GeV , 1000 fb^{-1})



6. Self-coupling:

$\Delta g_{\text{HHH}} / g_{\text{HHH}} \sim 20\%$
(200 GeV , 2000 fb^{-1})



PRECISION HIGGS PHYSICS
ESTABLISHMENT OF DETAILED
MECHANISM OF EWSB

$$\Delta M_H \sim 50 \text{ MeV}$$

Spin/parity: angular distributions

CP properties

m -dependence of couplings:

$$H^0 \rightarrow b\bar{b}, c\bar{c}, \tau^+\tau^-, (t\bar{t})$$

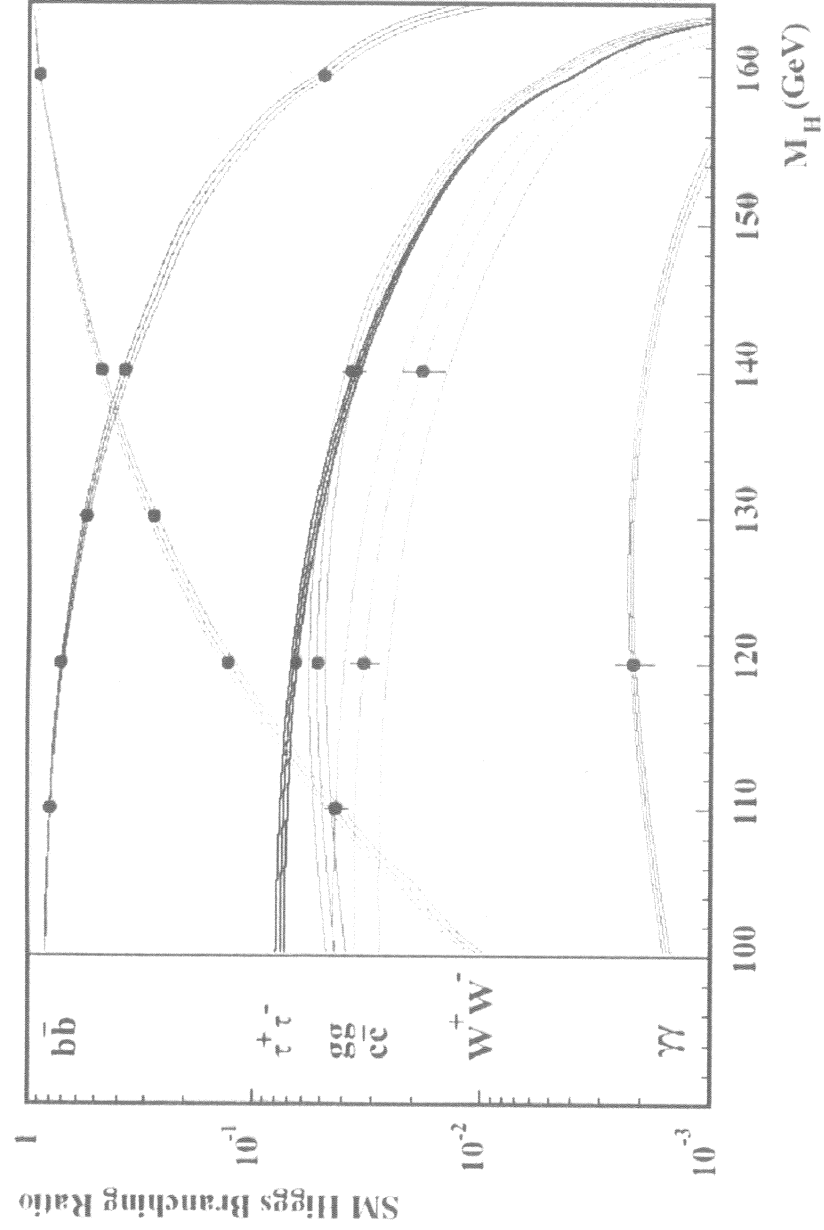
Gauge couplings to W, Z^0

Yukawa coupling to top: $e^+e^- \rightarrow t\bar{t}H^0$

Higgs self-coupling: $e^+e^- \rightarrow Z^0 H^0 H^0$

Is it (are they) the SM, MSSM, mSUGRA

... Higgs(es)?



e^+e^- Search Strategy

(Will start after first LHC results)

1. $\sqrt{s} \approx 300 \rightarrow 500$ GeV

Low-mass Higgs $\lesssim 400$ GeV

Light SUSY $\lesssim 250$ GeV

LF factory

2. $\sqrt{s} \approx 600 \rightarrow 1000$ GeV

Heavy Higgs $\lesssim 900$ GeV

SUSY $\lesssim 500$ GeV

New gauge bosons $\lesssim 5$ TeV

3. $\sqrt{s} \approx 1 \rightarrow 1.5$ TeV

Heavy SUSY $\lesssim 750$ GeV

New gauge bosons $\lesssim 10$ TeV

...

$\Rightarrow$ A 10-20 year comprehensive

programme of systematic energy
exploration in partnership with LHC

SUGRA in ATLAS TUR

Table 20-4 Masses in GeV for the five LHCC SUGRA points and the large $\tan\beta$ SUGRA point listed in Table 20-3. The first and second generation squarks and sleptons are degenerate and so are not listed separately. The SUSY masses for the five LHCC points are from ISAJET 7.22 [20-15]; the Higgs masses are from SPYTHIA 2.08 [20-16] and use the approximate two-loop effective potential. The masses for Point 6 are from ISAJET 7.37 [20-15].

Particle	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
$\tilde{g}$	1004	1009	298	582	767	540
$\tilde{\chi}_1^+$	325	321	96	147	232	152
$\tilde{\chi}_2^+$	764	537	272	315	518	307
$\tilde{\chi}_1^0$	168	168	45	80	122	81
$\tilde{\chi}_2^0$	326	321	97	148	233	152
$\tilde{\chi}_3^0$	750	519	257	290	497	286
$\tilde{\chi}_4^0$	766	538	273	315	521	304
$\tilde{u}_L$	957	963	317	918	687	511
$\tilde{u}_R$	925	933	313	910	664	498
$\tilde{d}_L$	959	966	323	921	690	517
$\tilde{d}_R$	921	939	314	910	662	498
$\tilde{t}_1$	643	710	264	594	489	365
$\tilde{t}_2$	924	933	329	805	717	517
$\tilde{b}_1$	854	871	278	774	633	390
$\tilde{b}_2$	922	930	314	903	663	480
$\tilde{e}_L$	490	491	216	814	239	250
$\tilde{e}_R$	430	431	207	805	157	219
$\tilde{\nu}_e$	486	485	207	810	230	237
$\tilde{\tau}_1$	430	425	206	797	157	132
$\tilde{\tau}_2$	490	491	216	811	239	259
$\tilde{\nu}_\tau$	486	483	207	806	230	218
h	95	116	69	112	93	112
H	1046	737	379	858	638	157
A	1044	737	371	859	634	157
$H^\pm$	1046	741	378	862	638	182

χ { }
 $\tilde{l}$ { }
 H { }

Majorana fermion, it has equal branching ratios into l^+X and l^-X , giving rise to isolated like-sign dileptons for which the Standard Model background is small. To estimate the reach for each signature, events were generated for many SUGRA points and for Standard Model processes using ISAJET plus a simplified detector simulation. Events were selected to have [20-18]

Just one example: new Z' mass reach.

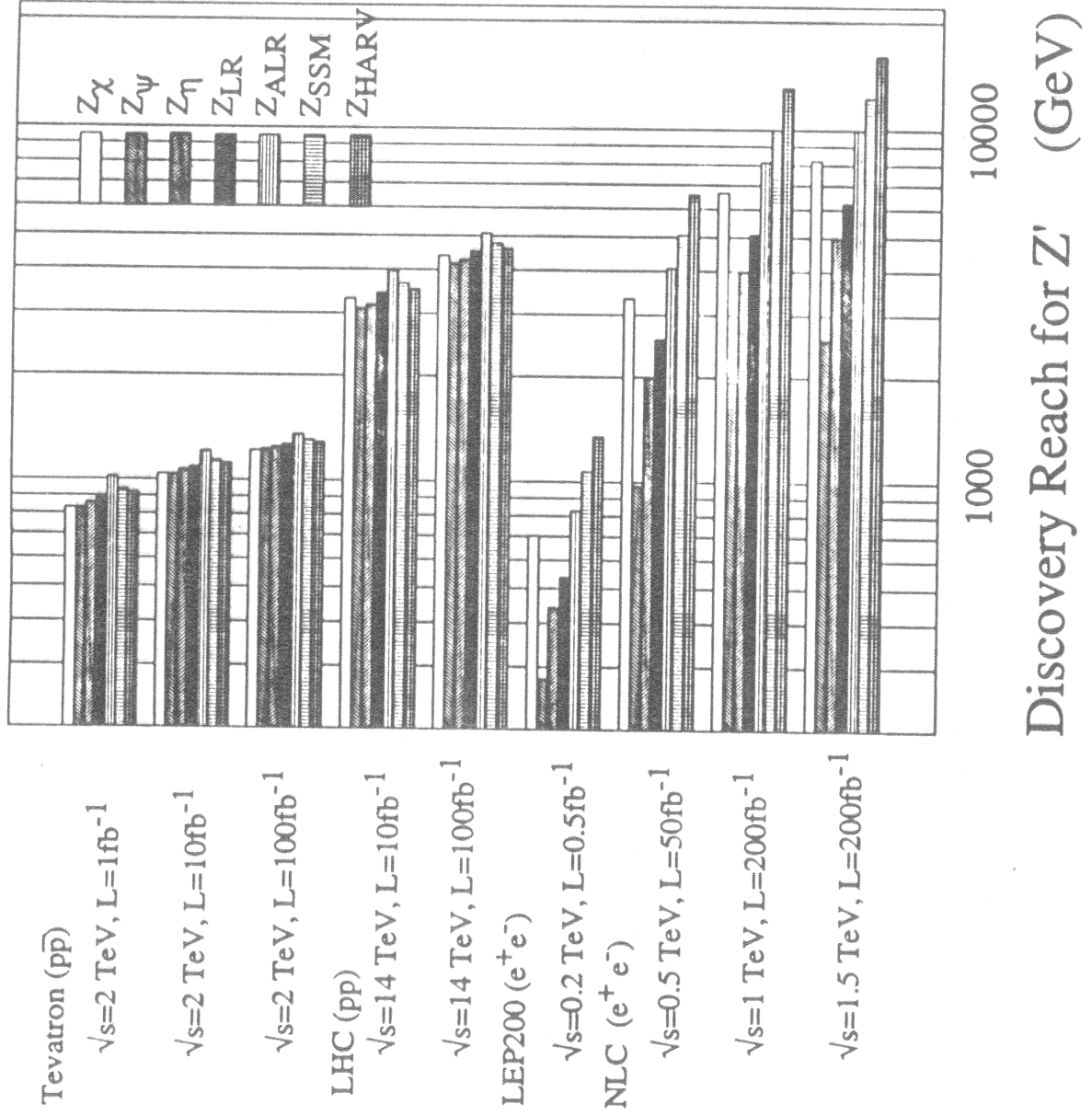


Figure 2.45: Tevatron and LHC bounds are based on 10 events in the $e^+e^- + \mu^+\mu^-$ channels; decays to SM final states only is assumed. LEP and NLC bounds are 99% CL using the observables σ_I , R^{had} , A'_{LR} and A^{had}_{LR} .

Sensitivity to Extra Dimensions at Weak Scale

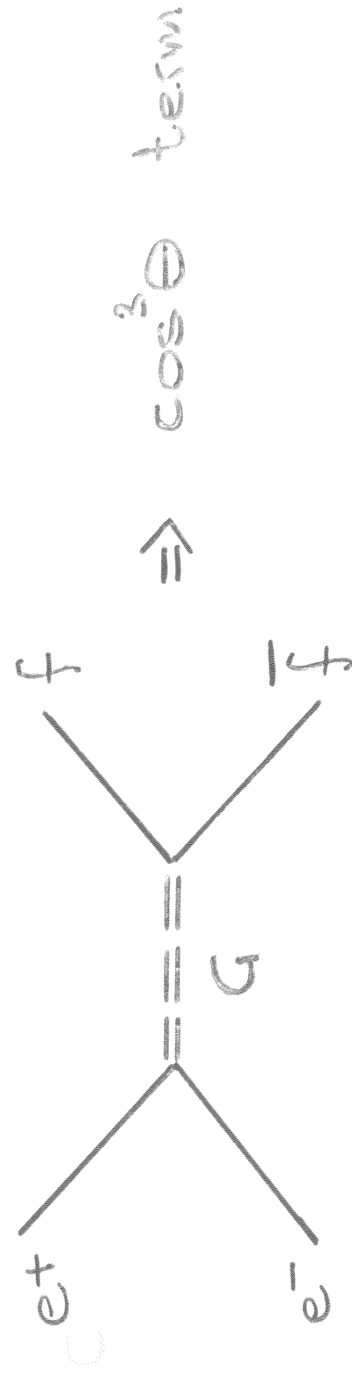
- Only 1 fundamental scale. - EWSB scale.
- Gravity strong in n dimensions; compactified

$\Rightarrow$ New processes in e^+e^- annihilation:

Graviton tower emission



Graviton tower exchange



$\Rightarrow 1 \text{ TeV LC: } M \gtrsim 5-10 \text{ TeV}$

The Guaranteed Programme at 300-500 GeV

- Light (SM) Higgs:

Mass

Decays: $H^0 \rightarrow b\bar{b}, c\bar{c}, \tau^+\tau^-$..
Couplings

- Low-mass SUSY...

Masses, couplings

- Precision $t\bar{t}$ physics:

$\Delta M_t \sim 100 \text{ MeV}$

Couplings to Z^0

Anomalous moments

Decay modes: standard $t \rightarrow bW$

non-standard $t \rightarrow bH^+$

$t \rightarrow \tilde{t} \tilde{X}_1^0$

$t \rightarrow \tilde{b} \tilde{X}_1^+$

Yukawa coupling

- W, Z physics:

TGC

Strong W

Z'

- QCD + $\gamma\gamma$ physics

eg. running of α_s : GUT constraints

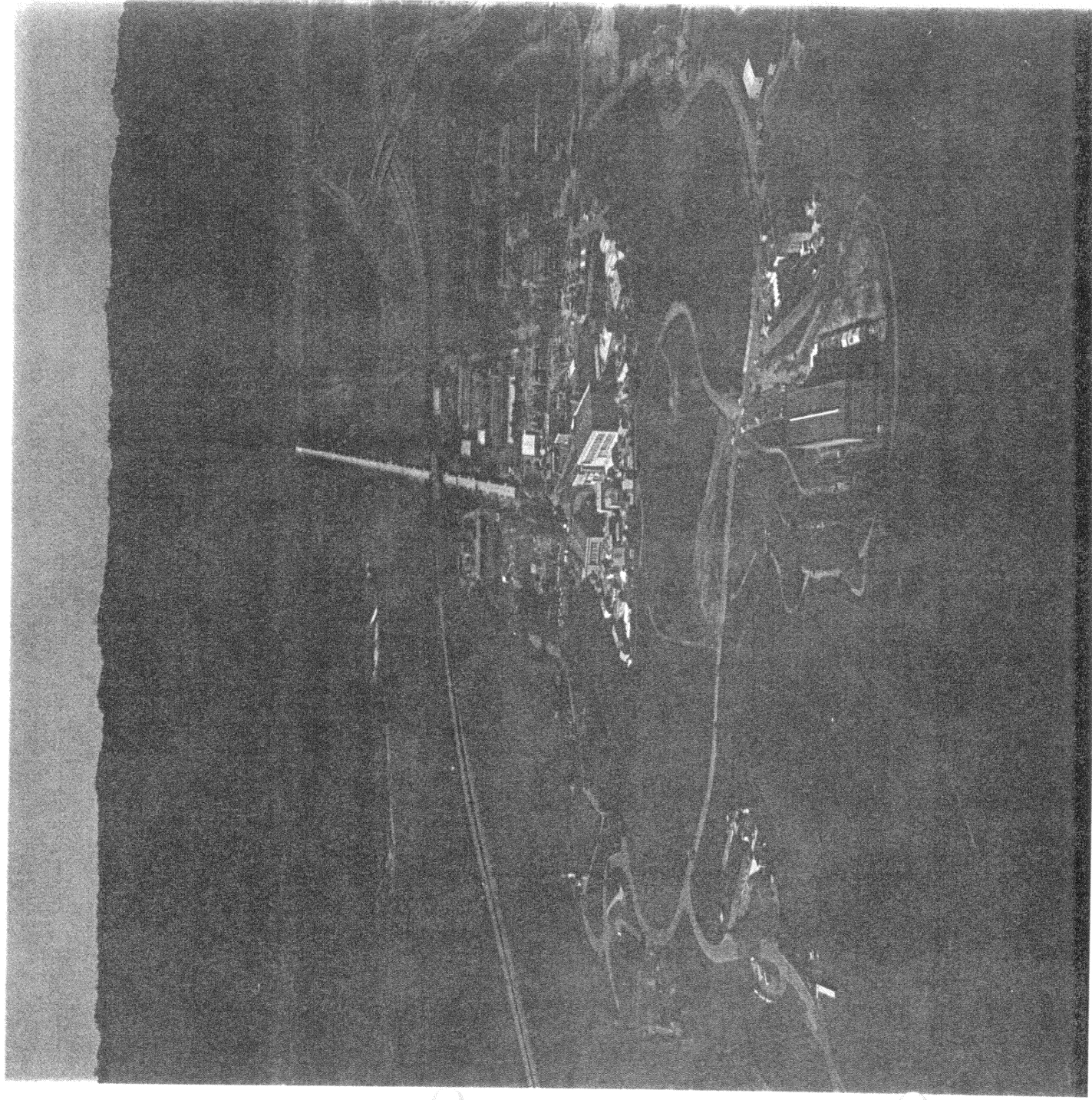
light gluinos

$\vdots$

LINEAR e^+e^- COLLIDERS: ACCELERATOR ACTIVITY

- 3 decades of e^+e^- storage rings
- 1st linear collider, SLC, operating 10 years
- SLAC/KEK collaborating on X-band linac design
- DESY pursuing superconducting linac design (TESLA)
- CERN thinking post-LHC: 2-beam accelerator
- SLAC, DESY, KEK committed to presenting design reports 2001-2002
 $\Rightarrow$ fully-costed accelerators and detectors
- Construction technically possible ≥ 2002

STANFORD LINEAR COLLIDER (SLC)



e^+e^- collisions @ $E_{cm} \sim 100 \text{ GeV}$

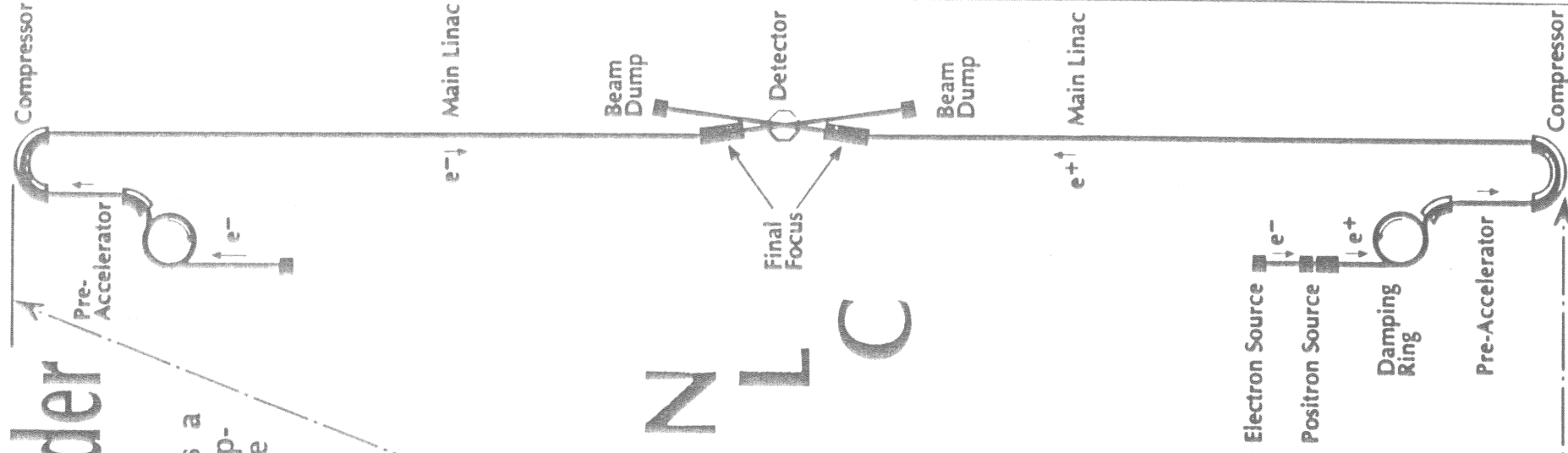
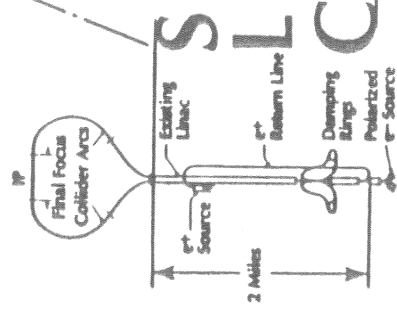
Next Linear Collider

Stanford Linear Accelerator Center is a world leader in research and development efforts towards a cost-effective Next Linear Collider (NLC).

The NLC will be 10 times more powerful than the SLC.

NLC

Stanford Linear Collider x10



OVERVIEW OF LINEAR COLLIDER DESIGNS

Europe:

TESLA	superc	1.3 GHz	800 GeV
CLIC	2-beam	30 GHz	3000 GeV

US:

NLC	X-band	11.4 GHz	1000 GeV
-----	--------	----------	----------

Japan:

JLC	X-band	11.4 GHz	1000 GeV
	C-band	5.7 GHz	500 GeV

However ...

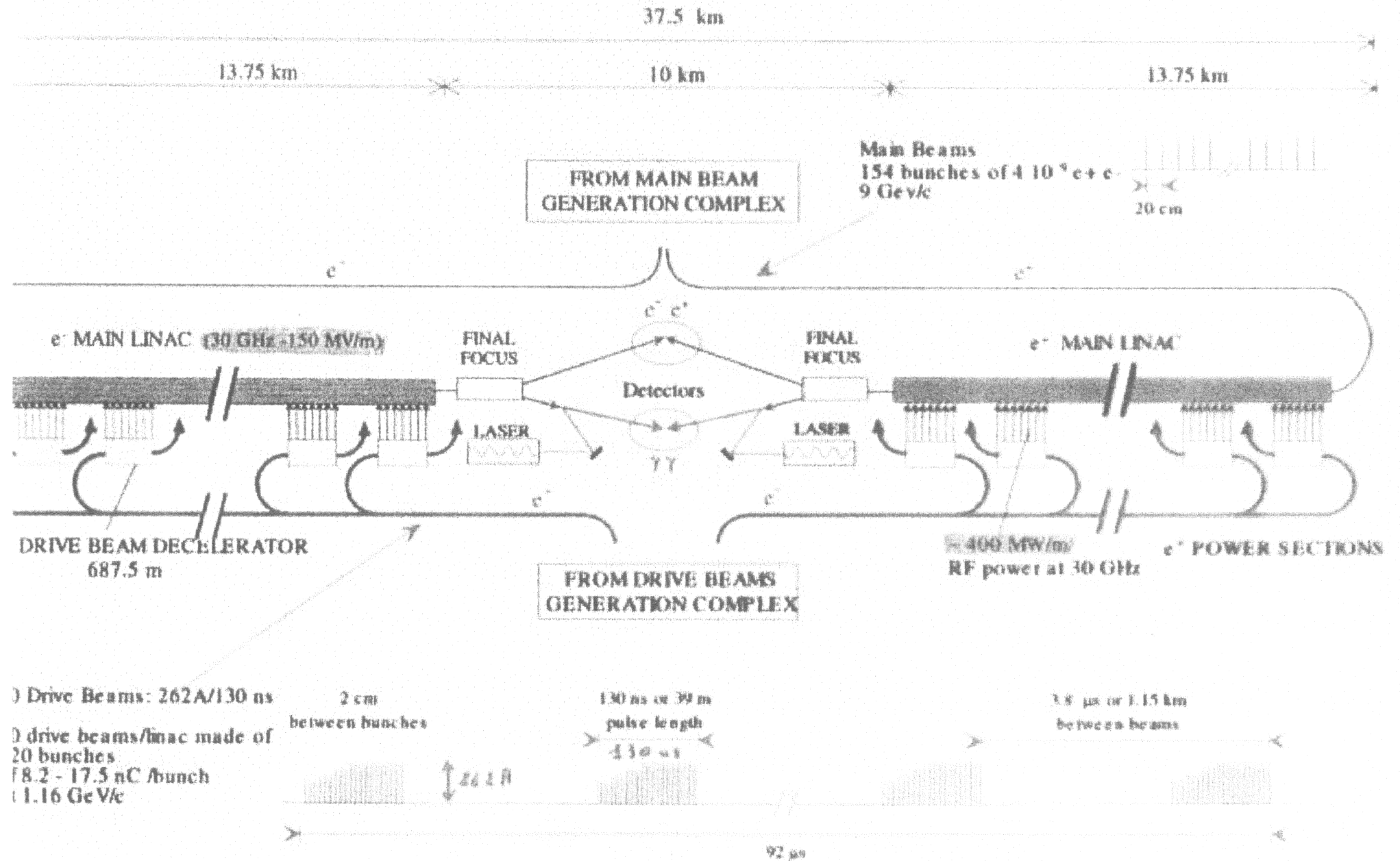
C-BAND JLC

- Limited to 500 GeV
 - ⇒ not energy-upgradeable
- Limited support in Japan
 - ⇒ 4 FTEs at KEK
- X-band preferred by KEK management
 - ⇒ MoU with SLAC on collaboration

CLIC

- Replace klystrons with low-E, high-I drive beam
 - Novel technology
 - Demo of principle in 3m section at CERN
 - Extensive R&D $\Rightarrow$ real accelerator design
 - CTF3 now funded at CERN
 - Only needed (and cost effective) for $E > 1000$ GeV
- $\Rightarrow$ possible technology for next-but-one collider?

Overall Layout of the CLIC complex at 3 TeV c.m.



NEXT-GENERATION MACHINE

TESLA: 800 GeV (35 MeV/m)

- Superconducting Nb cavities, 1.3 GHz RF

- Possible site: DESY

X-Band (NLC/JLC): 1000 GeV (75 MeV/m)

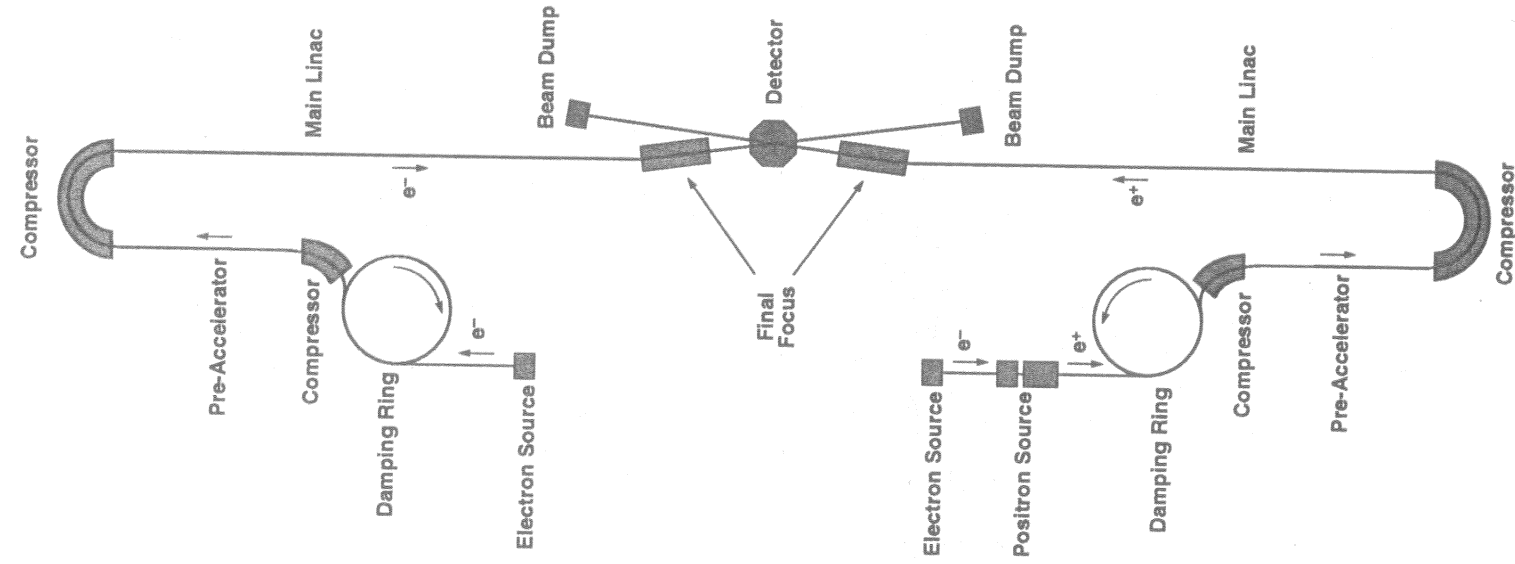
- Room-temp. Cu cavities, 11.4 GHz RF

- Possible sites:

US: near SLAC or FNAL

Japan: near KEK

Schematic of Next Linear Collider



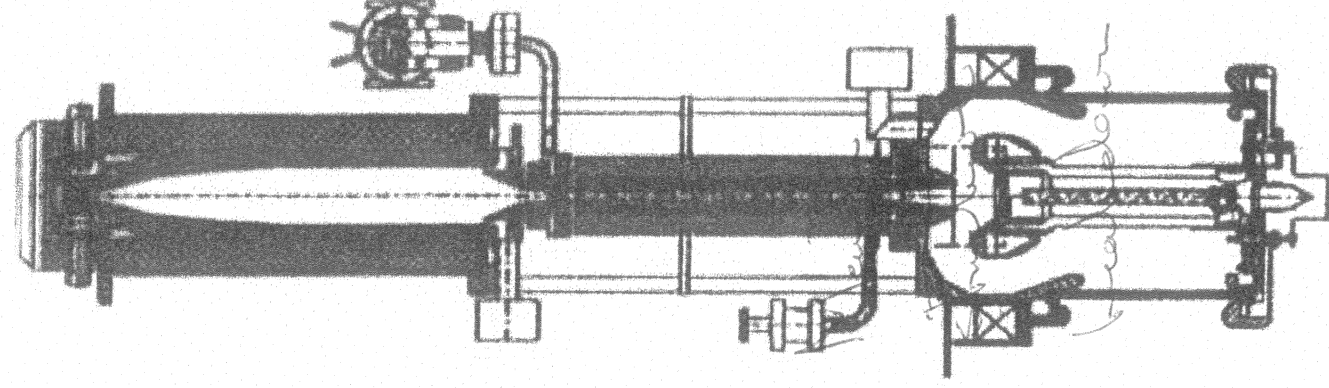
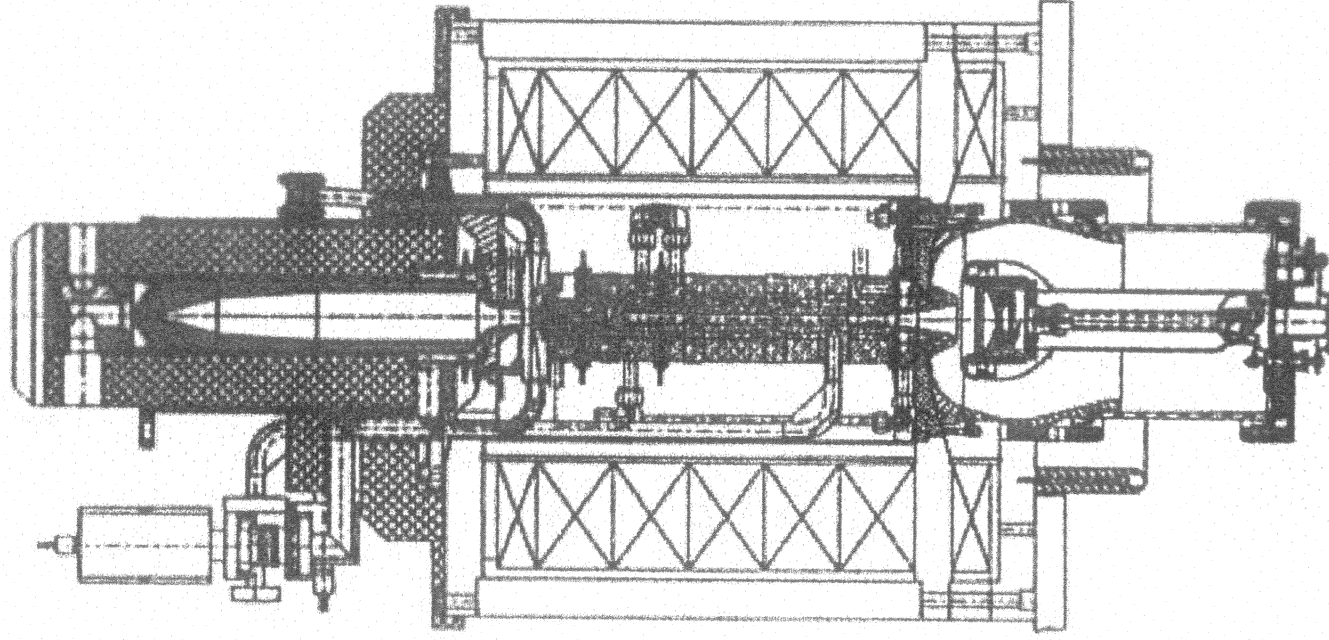
KLYSTRONS

Solenoid Focused

Periodic Permanent

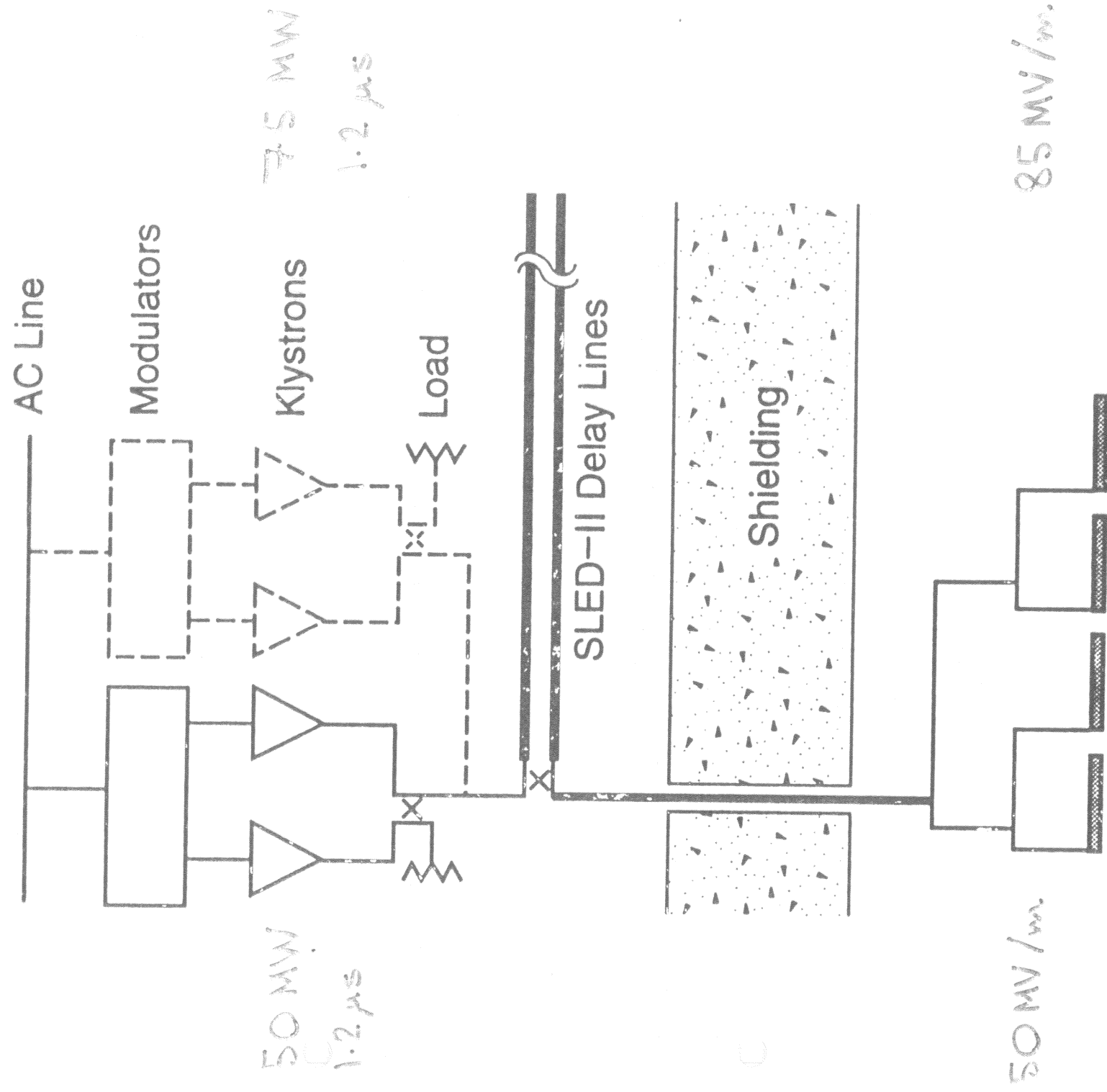
Solenoid Power = 25 kW

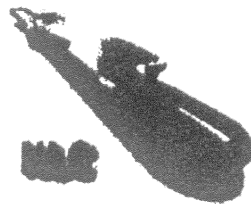
Magnet (PPM) Focused



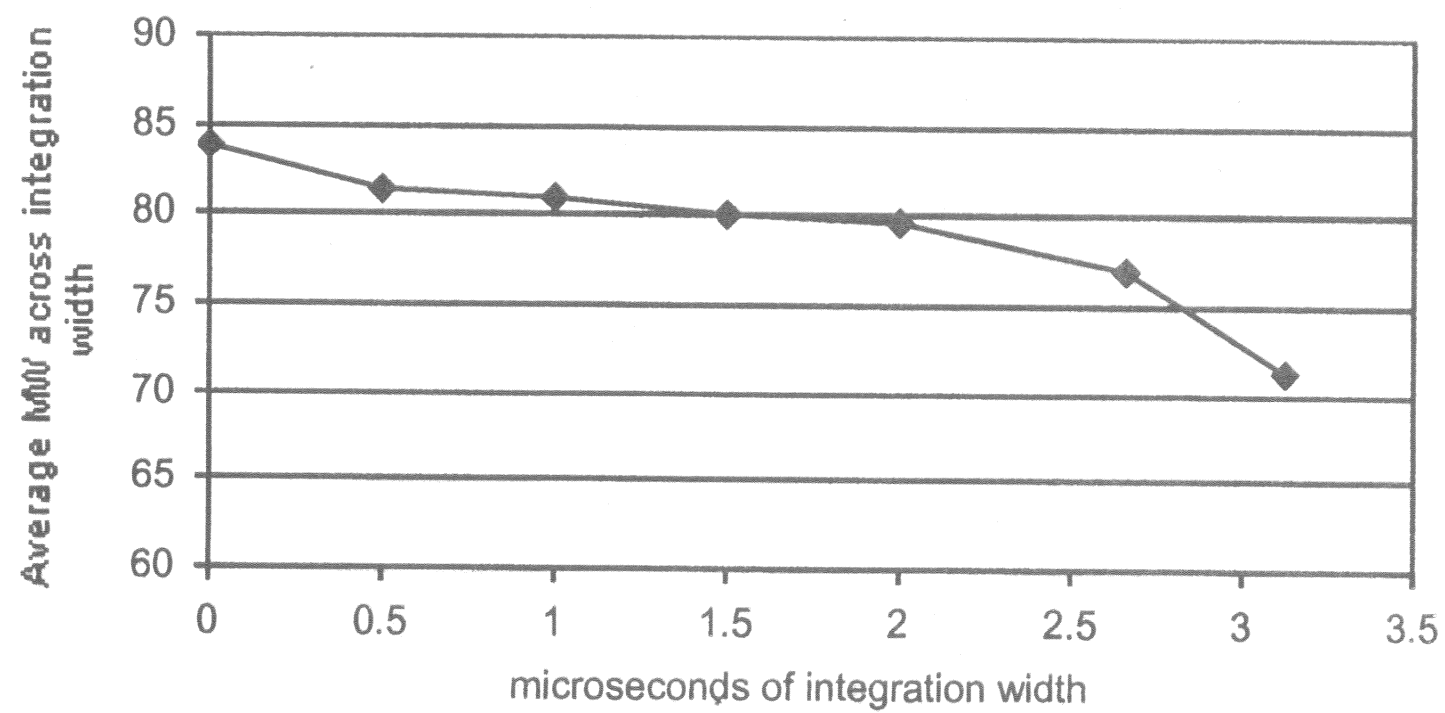
NLC RF System

500 GeV Required Parameters 1 TeV



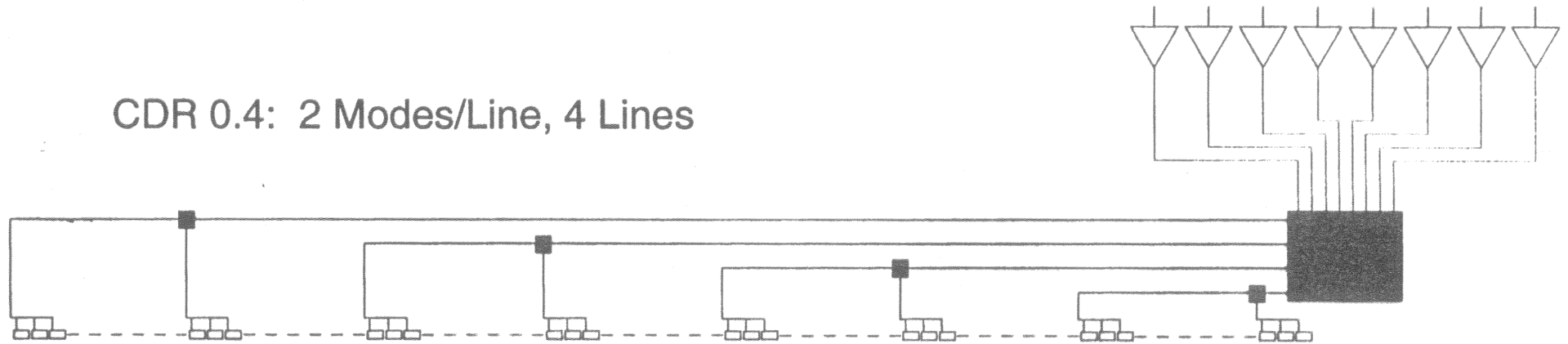


75MW PPM klystron XP-1 at 548kV peak and 14 capacitors,
eff=49% @ 80MW

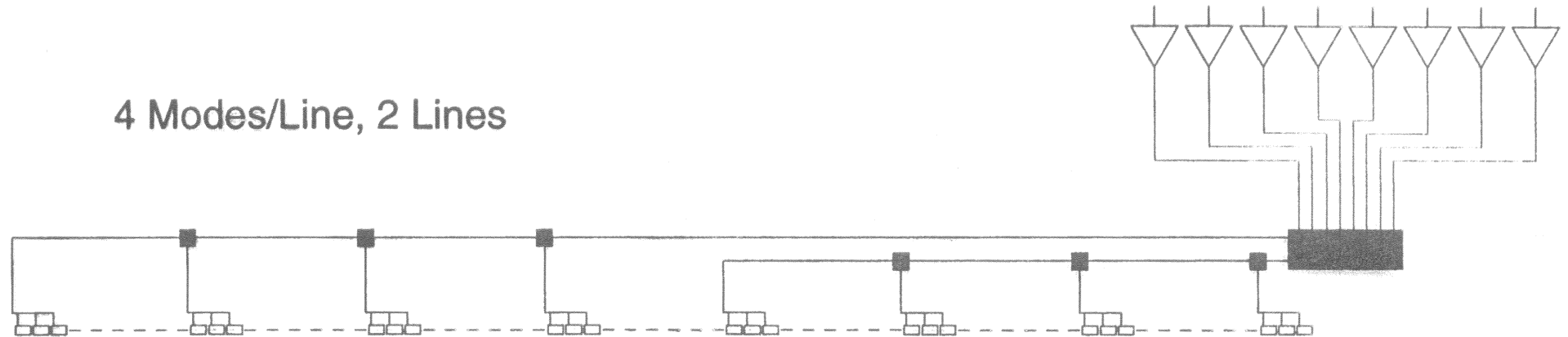


DLDS Options with Eight 75 MW Klystrons (3.05 μ s Pulse Width)

CDR 0.4: 2 Modes/Line, 4 Lines

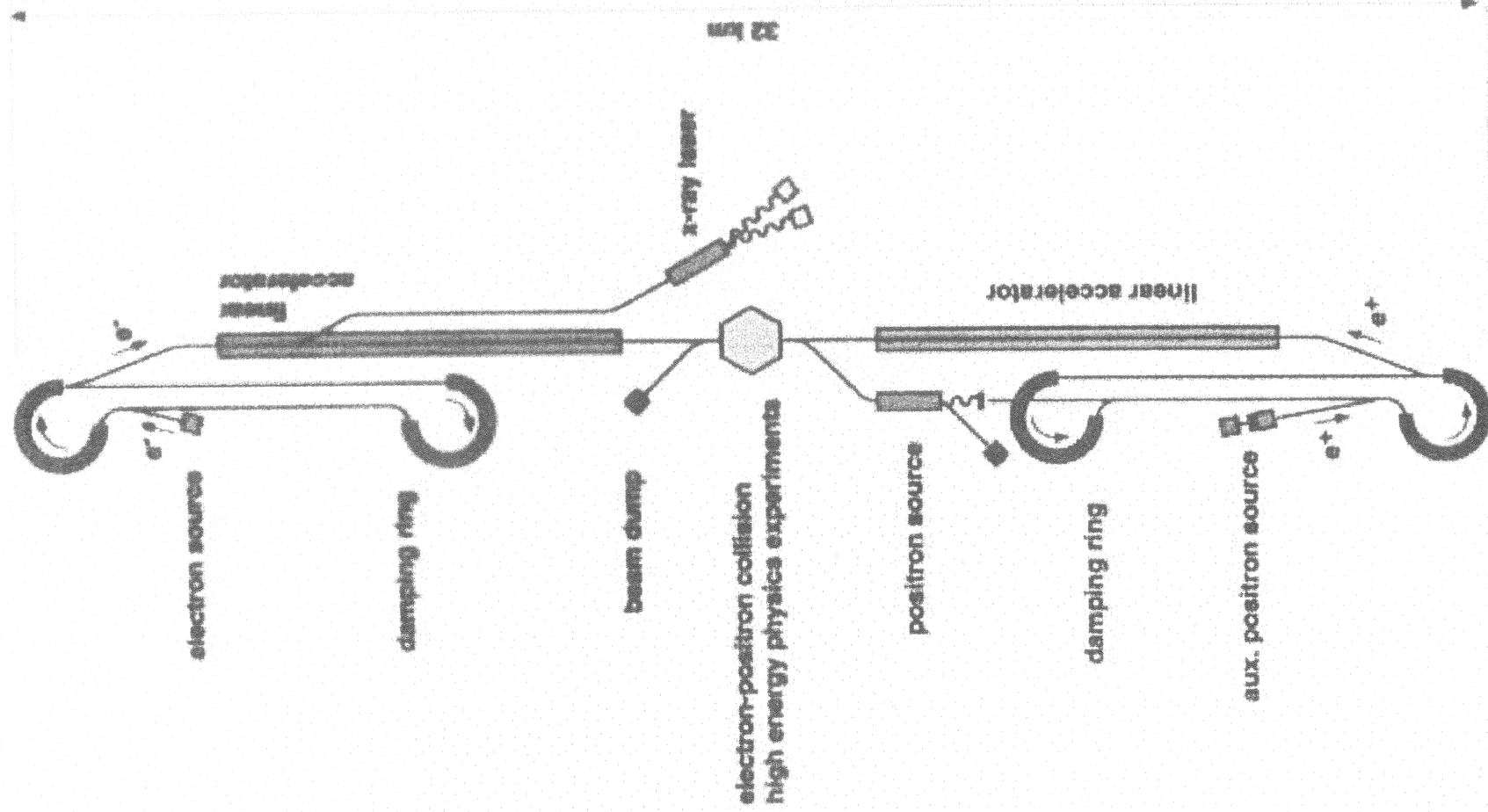


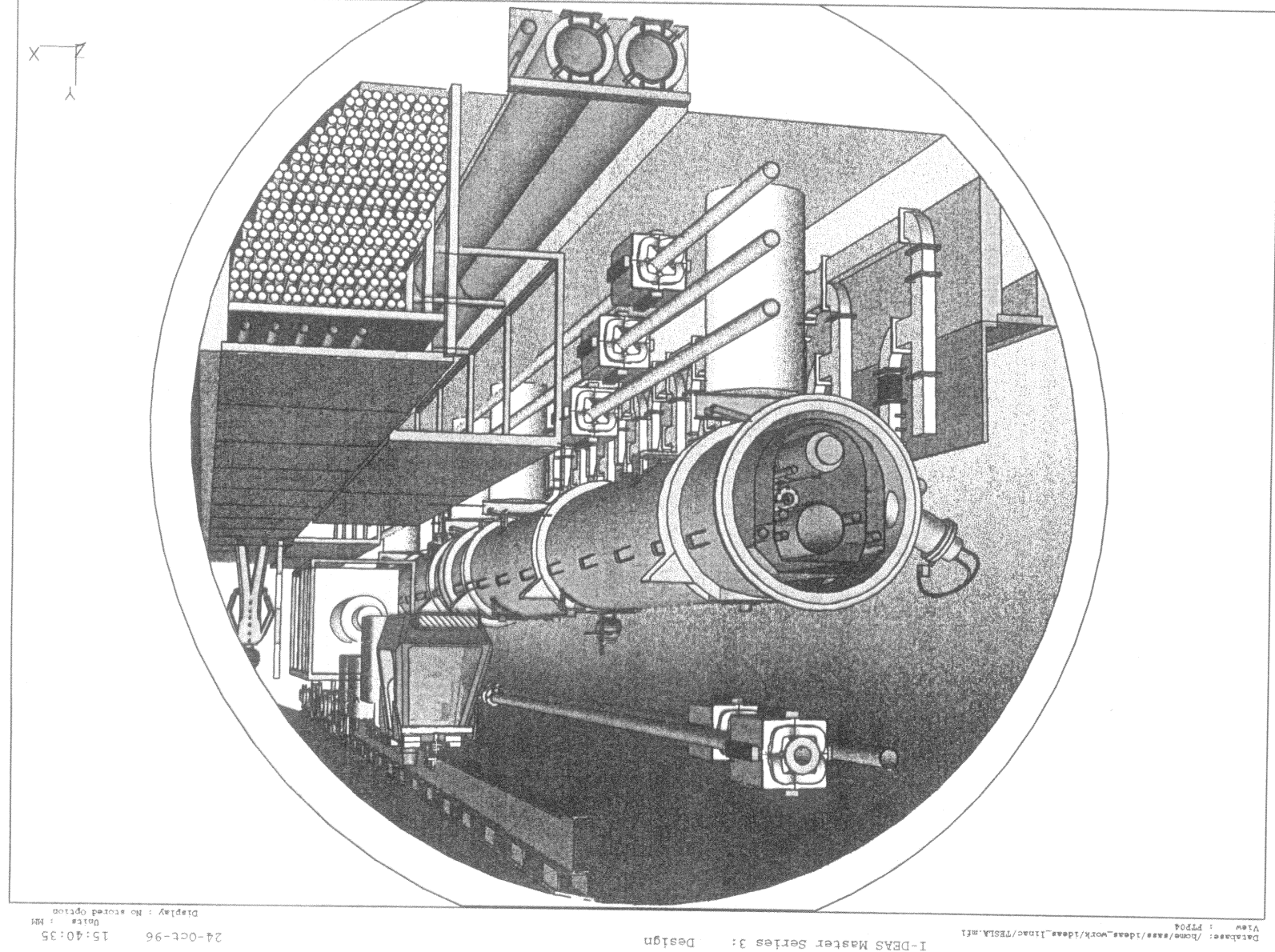
4 Modes/Line, 2 Lines



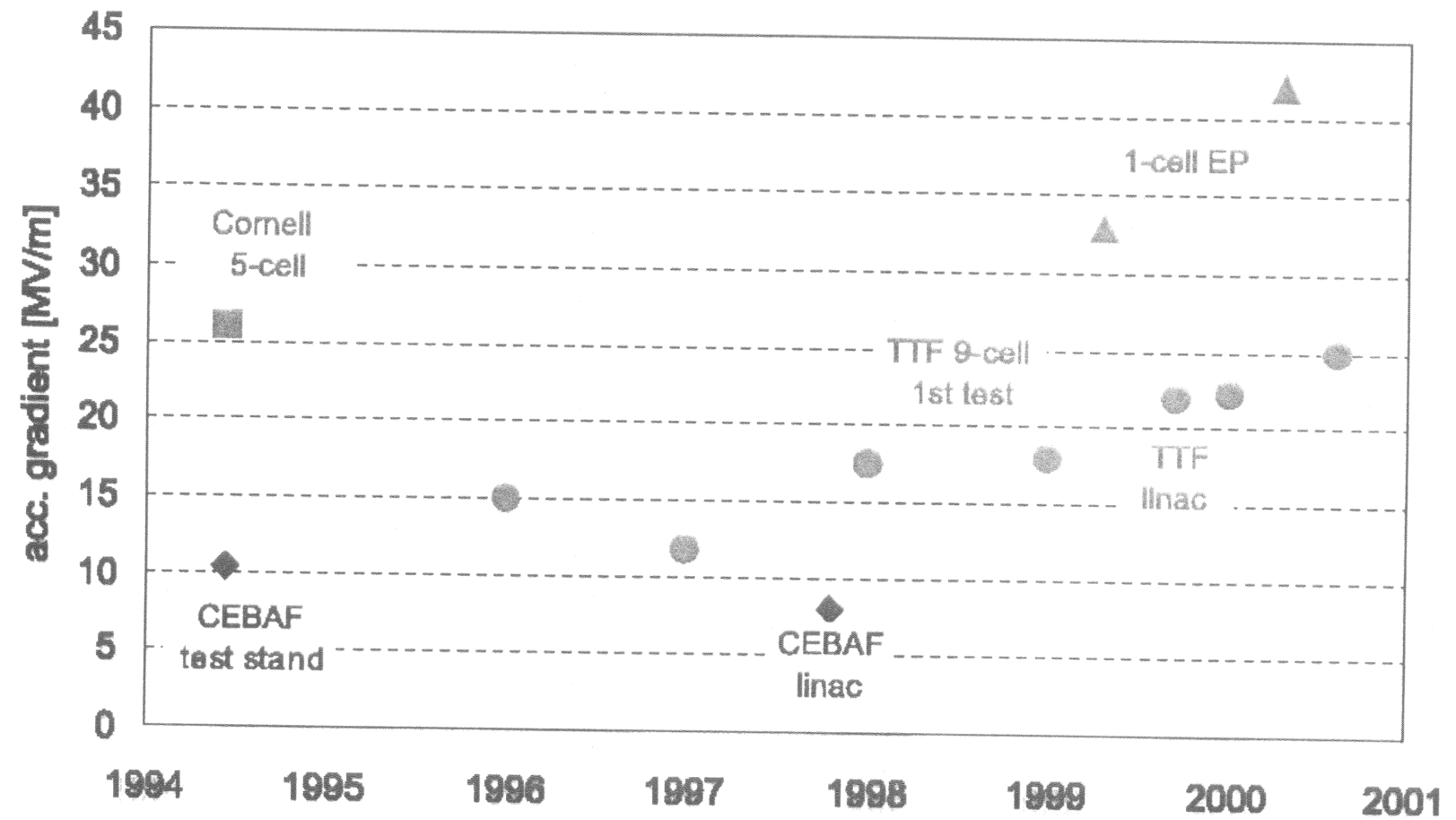
TESLA (DESY)

Superconducting RF (1.3 GHz)





Superconducting Cavity Performance



Technology Choices

Table 1.1: Linear collider design parameters ($E_{\text{cms}} = 500 \text{ GeV}$).

	Frequency (GHz)	Gradient (MV/m)	Total Length (km)	Beam Power (MW)	σ_y (nm)	Luminosity ($10^{33} \text{ cm}^{-2} \text{ s}^{-1}$)
SuperC	1.3	25 22	30	8.2 11	19 5	16 30
S-Band	3.0	21	30	7.3	15	5
X-Band	11.4	50	16 20	4.8	5.5	6
2-Beam	30.0	80	9	2.7 5	7.5 5	5 20

Luminosity

$$L = \frac{nN^2 H f}{4\pi\sigma_x^* \sigma_y^*} ,$$

n = number of bunches per train,
 N = number of particles per bunch,
 H = beam pinch enhancement,
 f = machine repetition rate,

$$L = \frac{1}{4\pi E} \frac{NH}{\sigma_x^*} \frac{P}{\sigma_y^*}$$

ILC-TRC



Table 1.1

Linear Colliders: Overall and Final Focus Parameters - 500 GeV (c.m.)

>

Click here to update your machine information for Table 1.1.	TESLA		SBLC		JLC (C)		JLC (X)	NLC	JLC/NLC**	VLEPP	
	TRC 12/95	Updated* 8/98	TRC 12/95	Updated* 10/96	TRC 12/95	Updated* 8/98	TRC 12/95	TRC 12/95	Updated* 12/98	TRC 12/95	Updated* 10/96
Initial energy (c.m.) (GeV)	500		500		500		500	500	500	500	
RF frequency of main linac (GHz)	1.3		3		5.7		11.4	11.4	11.4	14	
Nominal luminosity ($10^{33} \text{ cm}^{-2} \text{ s}^{-1}$) [†]	2.6	16.2	2.2	3.16	7.3	5.02	5.1	5.3	5.1(4.2)	12.3	11.9
Actual luminosity ($10^{33} \text{ cm}^{-2} \text{ s}^{-1}$) [†]	6.1	30	3.75	5.3	6.1	7.18	5.2	7.1	6.54(5.45)	9.3	9.7
Linac repetition rate (Hz)	10	5	50		100		150	180	120(100)	300	
No. of particles/bunch at IP (10^{10})	5.15	2	2.9	1.1	1	1.11	.63	.65	.95	20	
No. of bunches/pulse	800	2820	125	333	72		85	90	95	1	
Bunch separation (nsec)	1000	337	16	6	2.8		1.4		2.8	2.8	-
Beam power/beam (MW)	16.5	11.3	7.26	7.25	2.9	3.07	3.2	4.2	4.5(3.7)	2.4	
Damping ring energy (GeV)	4	3.2	3.15		2	1.98	2	2	1.98	3	
Unloaded/loaded ^{††} (MV/m)	25/25	21.7/21.7	21/17		40/32	45/36	73/58	50/37	72.3/55	100/91	
Total two-linac length (km)	29	30	33	32	18.8	16	10.4	15.6	10.5	7	
Total beam delivery length (km)	3	2.5	3		3.6		3.6	4.4	NA	3	
$\gamma\theta_x / \gamma\theta_y$ (m-rad $\times 10^{-6}$)	20/1	10/.03	10/.5	5/.25	3.3/.05		3.3/.05	5/.05	4.5/0.1	20/.08	

LINEAR e^+e^- COLLIDERS: RESUME OF NLC/JLC + TESLA PROJECTS

- $e^\pm$ source:
 ~ 100 bunches $\times 10^{10}$ @ 180 Hz (X-band)
 ~ 3000 bunches $\times 2 \cdot 10^{10}$ @ 5 Hz (TESLA)
- Maintain high polarisation with $\Delta\tau_{bunch} \sim 3\text{ns}$

- Damping rings:
 $\epsilon_x \sim 10^{-9}\text{mrad}$, $\epsilon_y \sim 10^{-11}\text{mrad}$

- Linac:

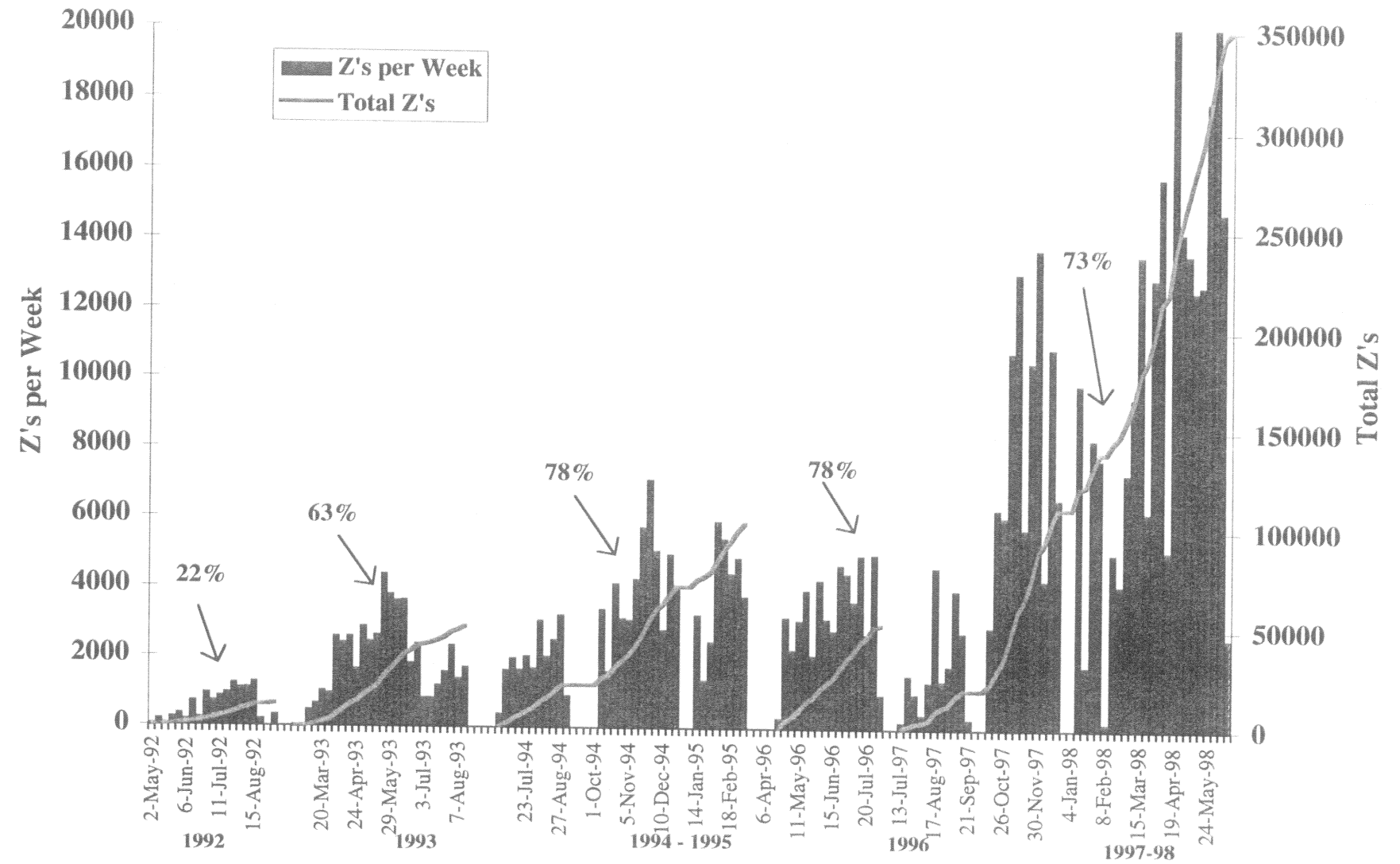
X-band gradient $\Rightarrow 55\text{ MV/m}$	} 500 GeV
TESLA gradient $\Rightarrow 22\text{ MV/m}$	

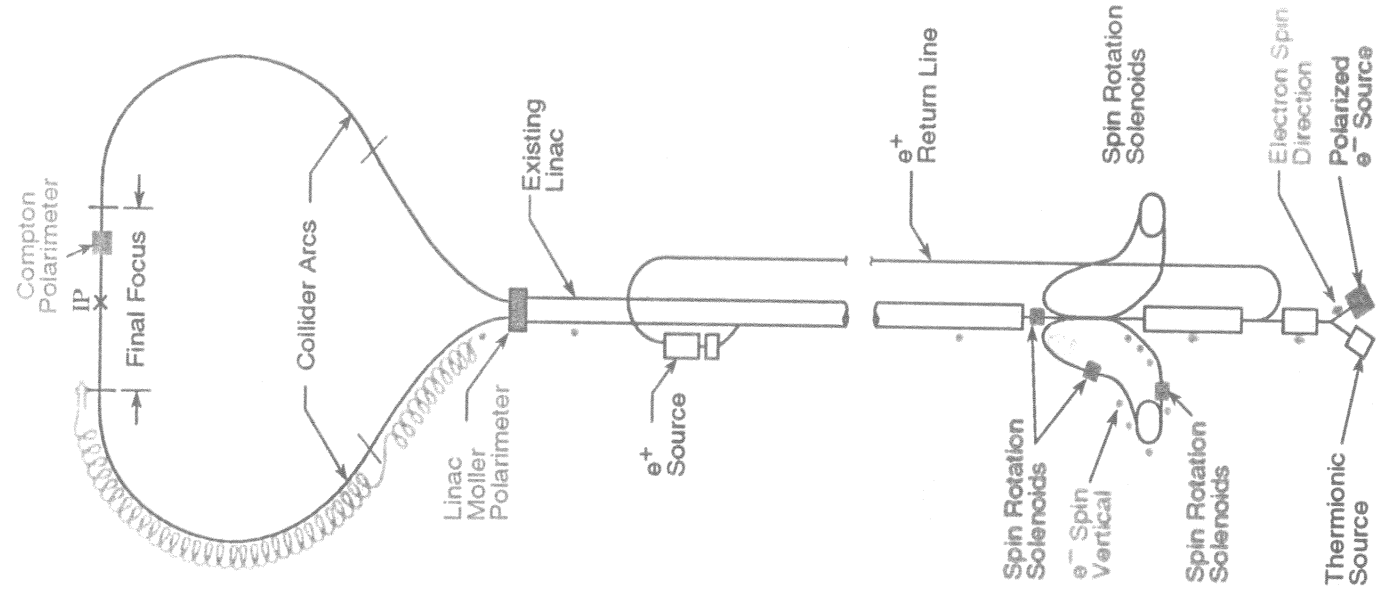
- Final focus:
 Demagnification $\times 250$

Table 1.2: Linear collider test facilities around the world.

Facility	Location	Goal	Operations
SLC	SLAC	Prototype Collider	1988
ATF	KEK	Injector and Damping Ring	1995
TTF	DESY	SuperC Linac	1997
SBTF	DESY	S-band Linac	1996
NLCTA	SLAC	X-band Linac	1996
CTF	CERN	2-Beam Linac	1996
FFTB	SLAC	Final Focus/IR	1994

1992 - 1998 SLD Polarized Beam Running





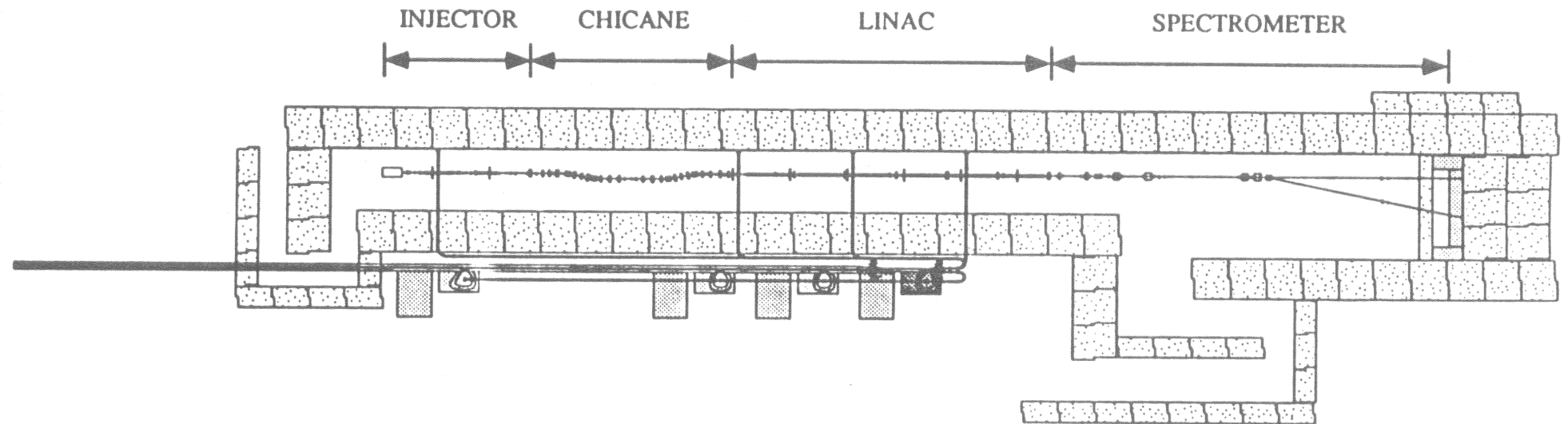
Polarization in the Overall SLC Layout

2-94

7615A13

Complete 1 GeV prototype linac.

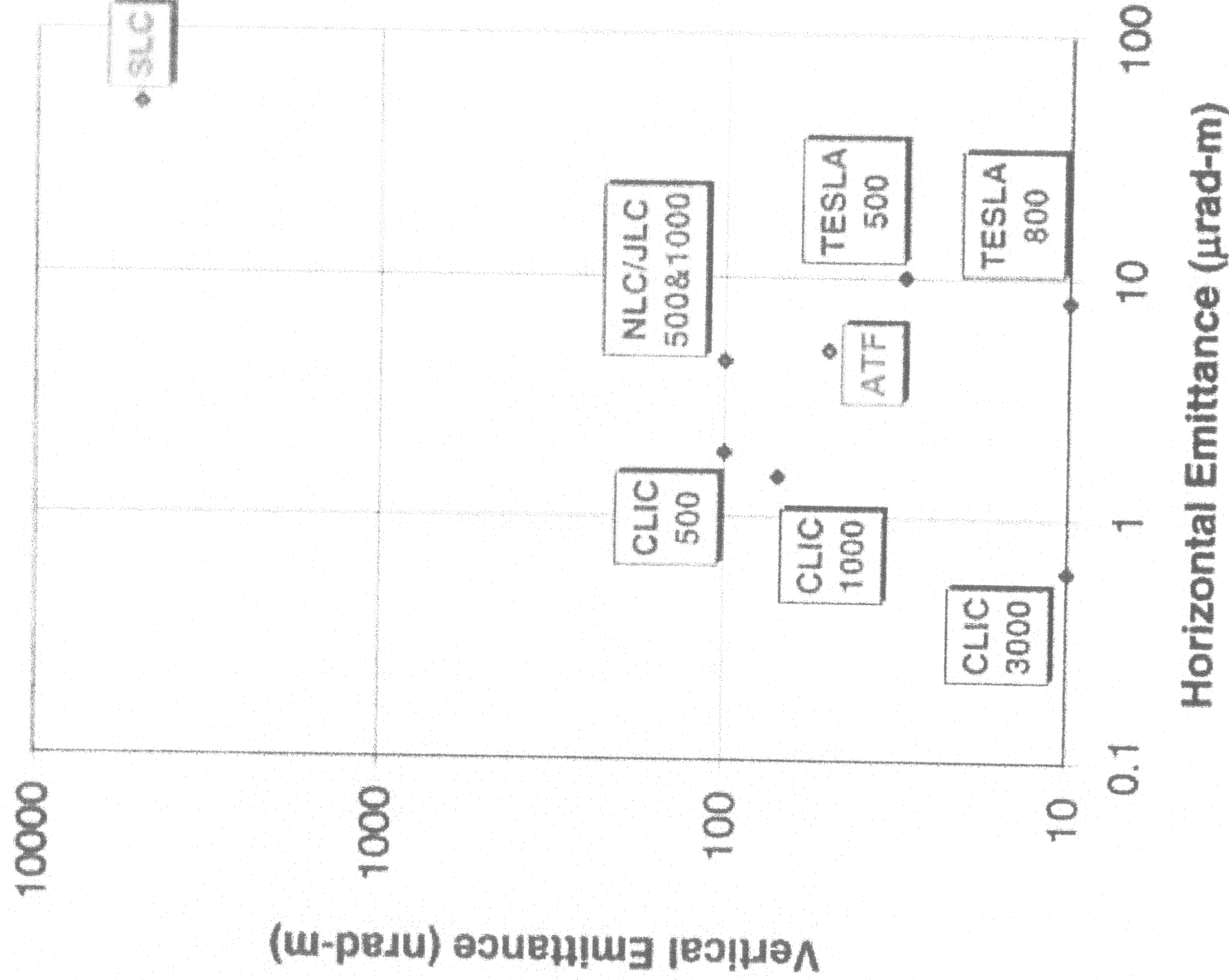
NEXT LINEAR COLLIDER TEST ACCELERATOR (NLCTA)



Operating now

SIAC

Normalized beam emittances in Linear Colliders



• in operation

ATF Collaboration

KEK
SLAC
DESY
BINP (Protvino)
Pohang
Ching Hua (Beijing)

Collaboration Meeting at SLAC in November 1996

Collaboration Meeting at KEK in June 1997

SLAC Participation

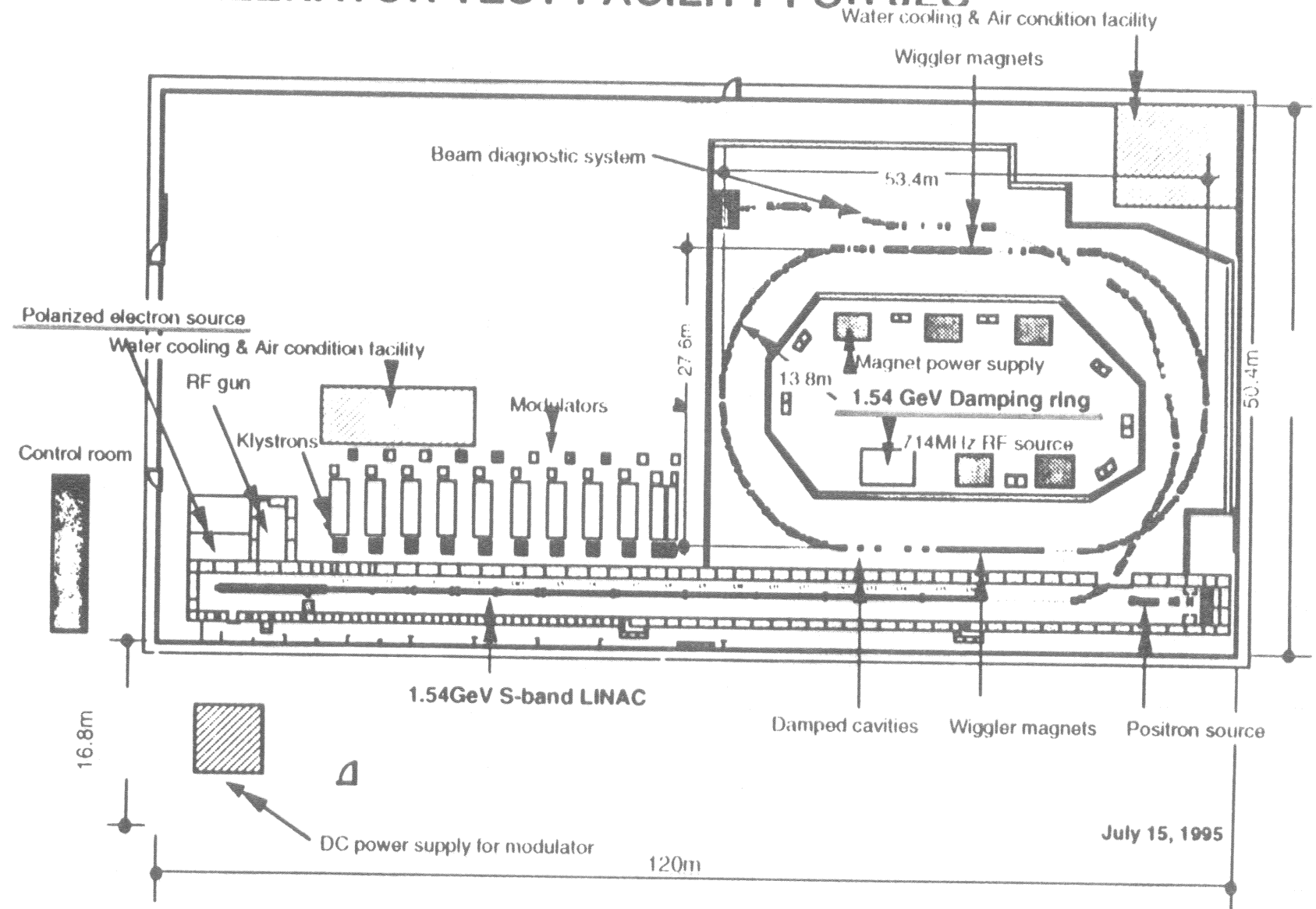
Design
Electron Source
Ring

Hardware
Injector S-Band RF
Injection Kickers and Power Supplies
Wire Scanner/Instrumentation Design

Commissioning (4-5 MM in FY97 to date)
Hardware and instrumentation checkout
Software development
Beam tuning and operations

K.L.K.

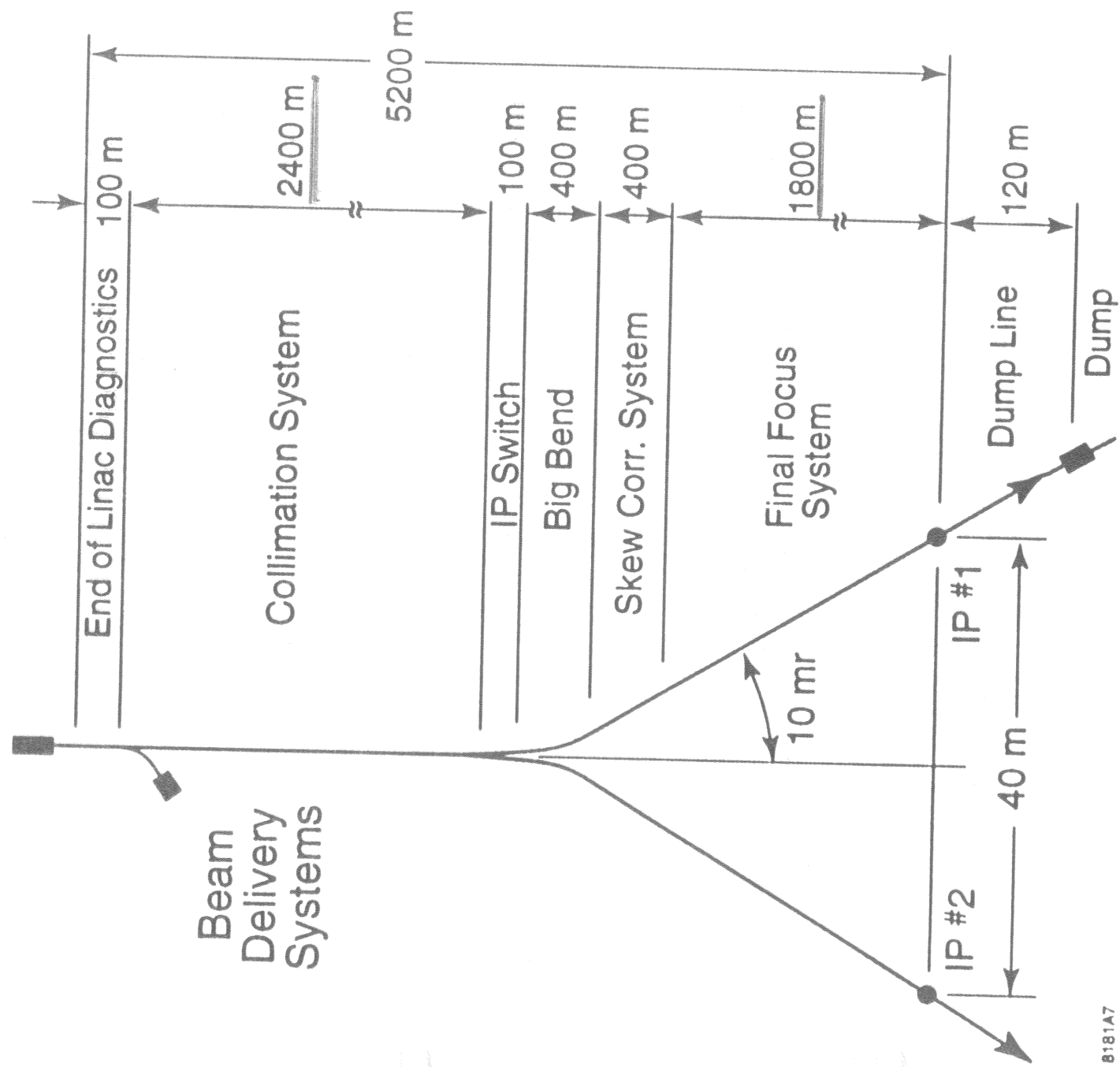
ACCELERATOR TEST FACILITY FOR JLC



July 15, 1995

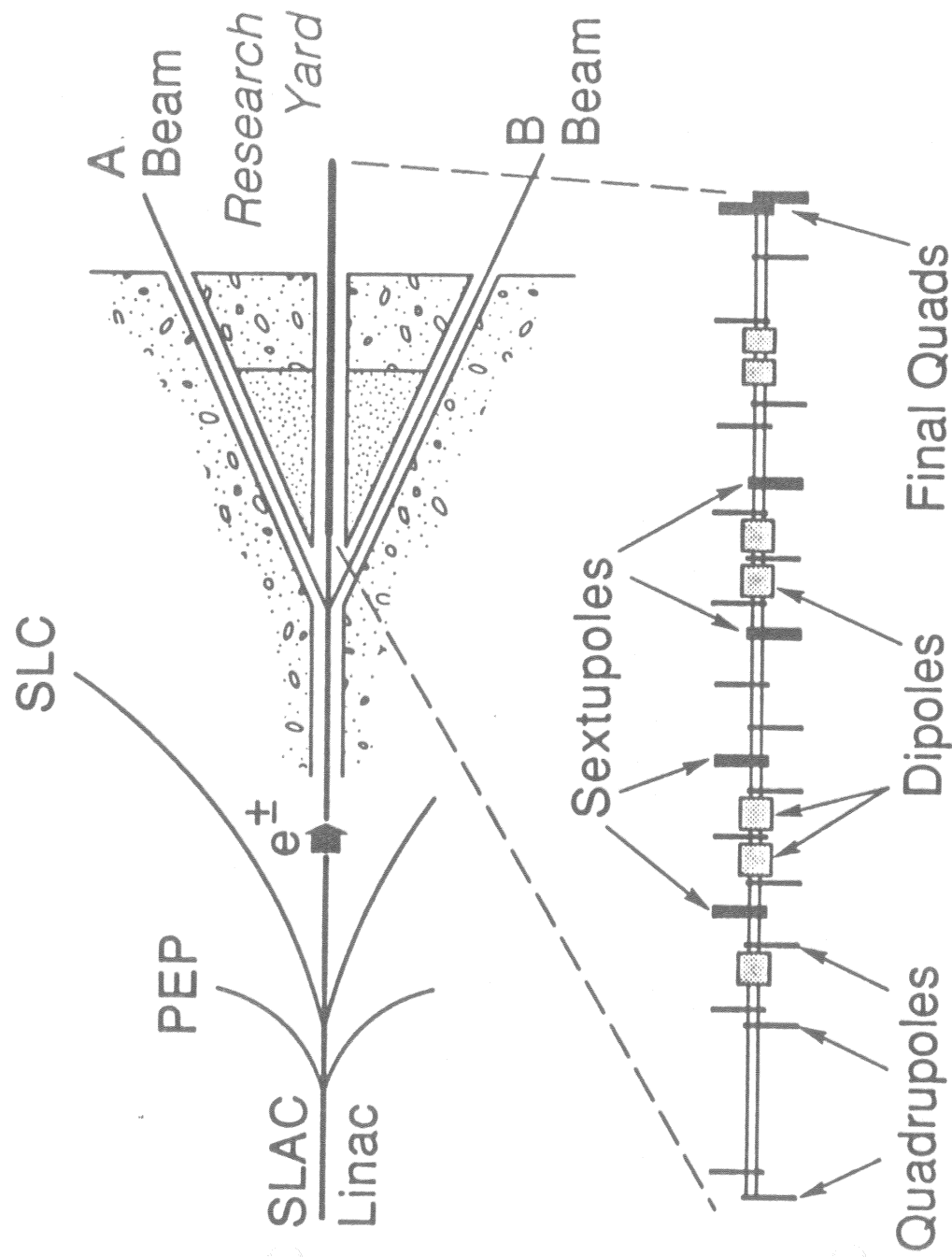
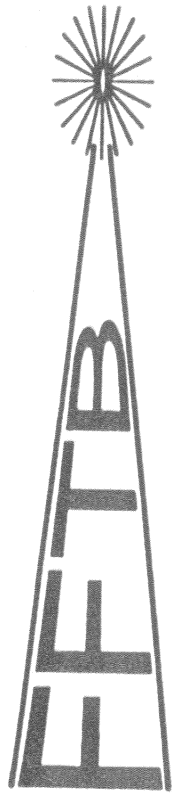
Operational now

Beam Delivery + Final Focus

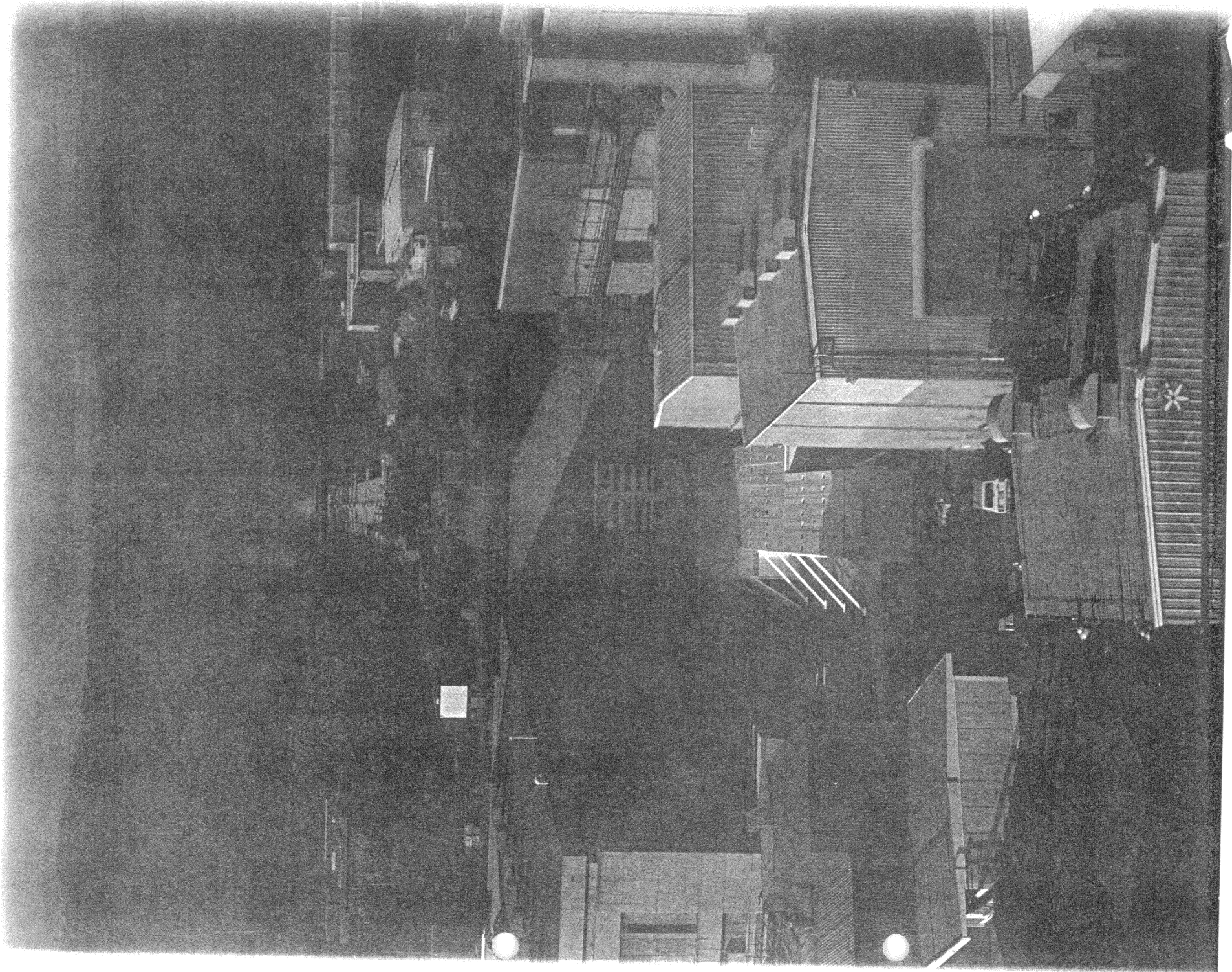


FFTB Collaboration Responsibilities

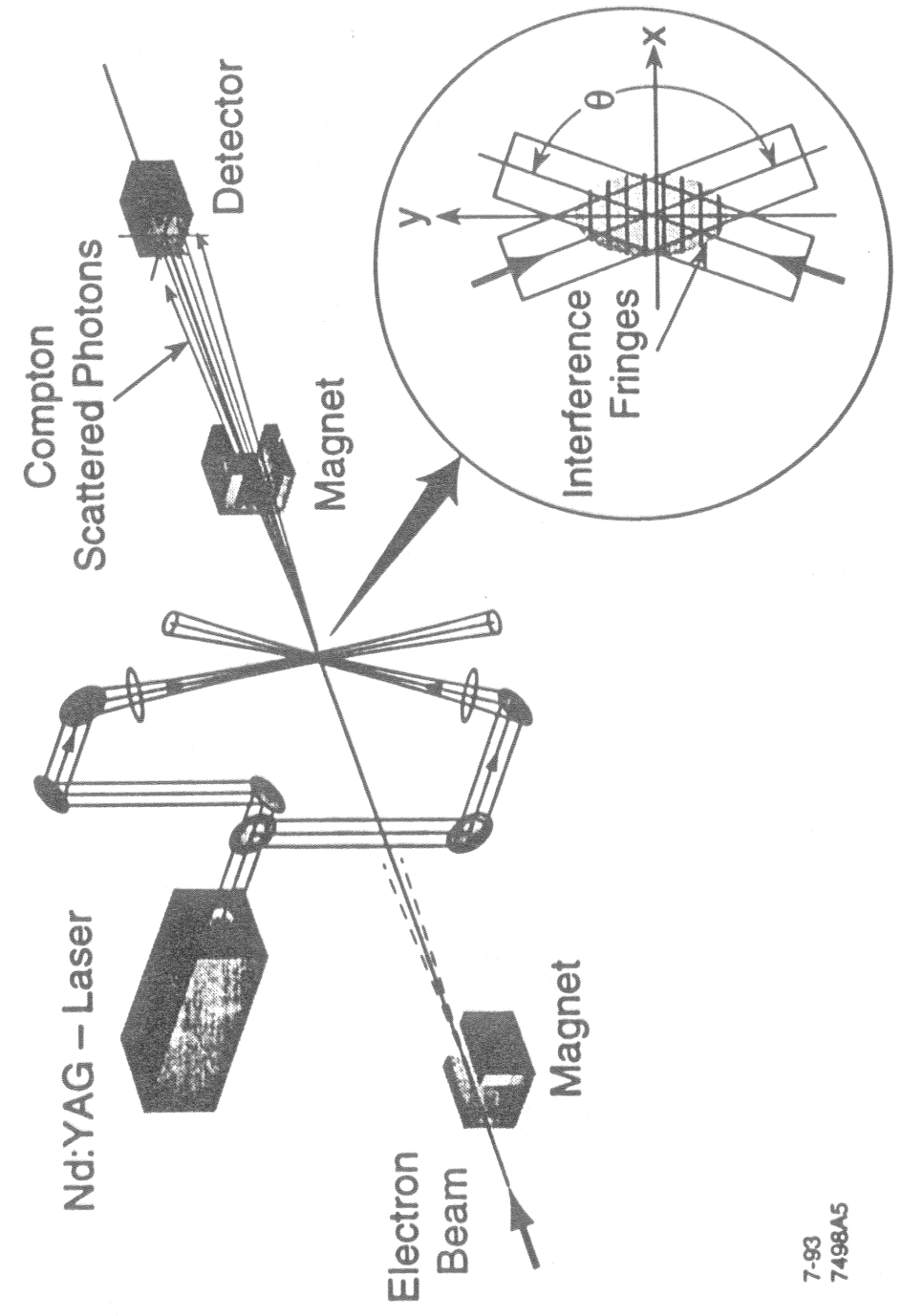
BINP	Magnets
DESY	Alignment Instrumentation
FNAL	Collimators Optics Analysis
KEK	Instrumentation Final Quad Package Optics Design and Analysis
LAL(Orsay)	Instrumentation Optics Design
MPI(Munich)	Magnet Movers
SLAC	SLC Beam Power Supplies Instrumentation Alignment Facilities Optics Design and Analysis



Final Focus Test Beam

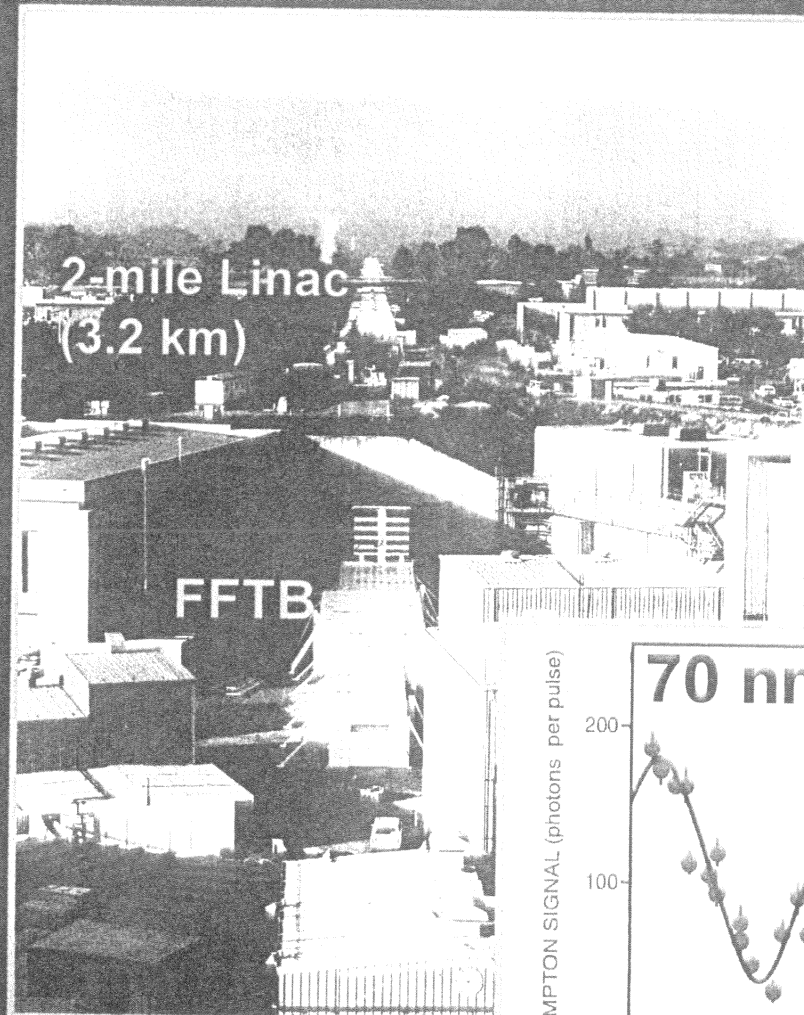


Shitake Spot-size Monitor

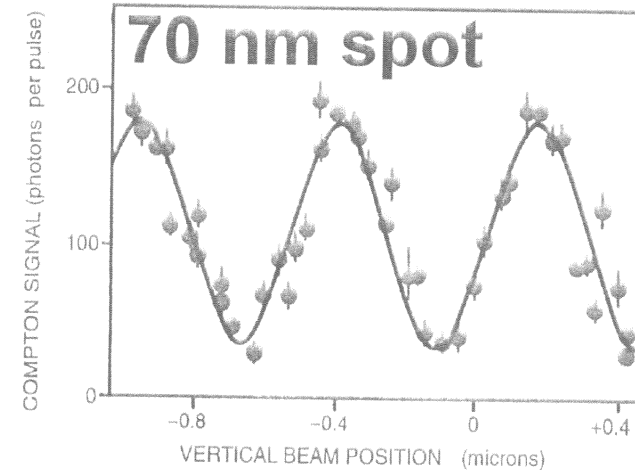
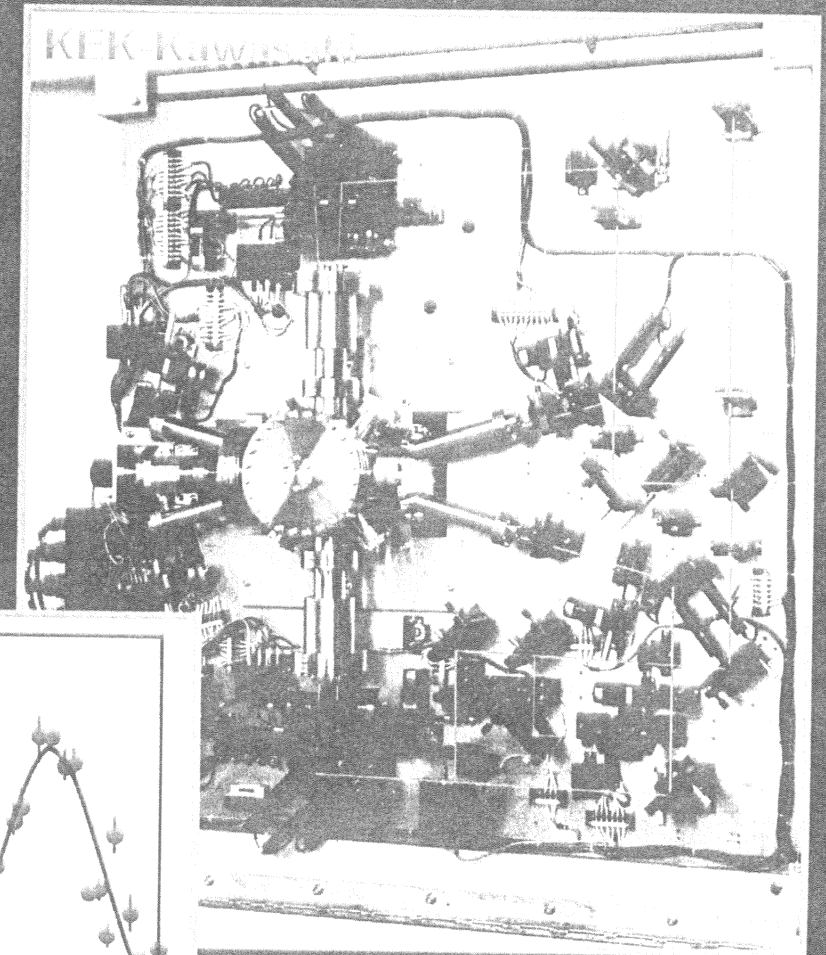


Experimental Test at FFTB

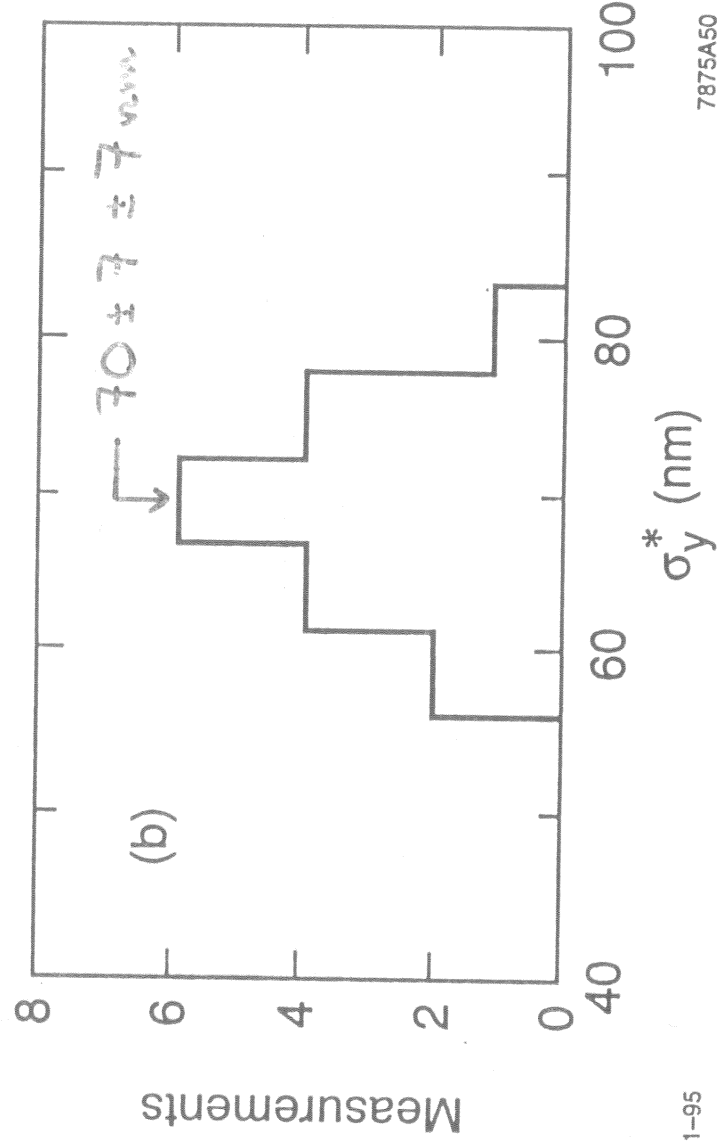
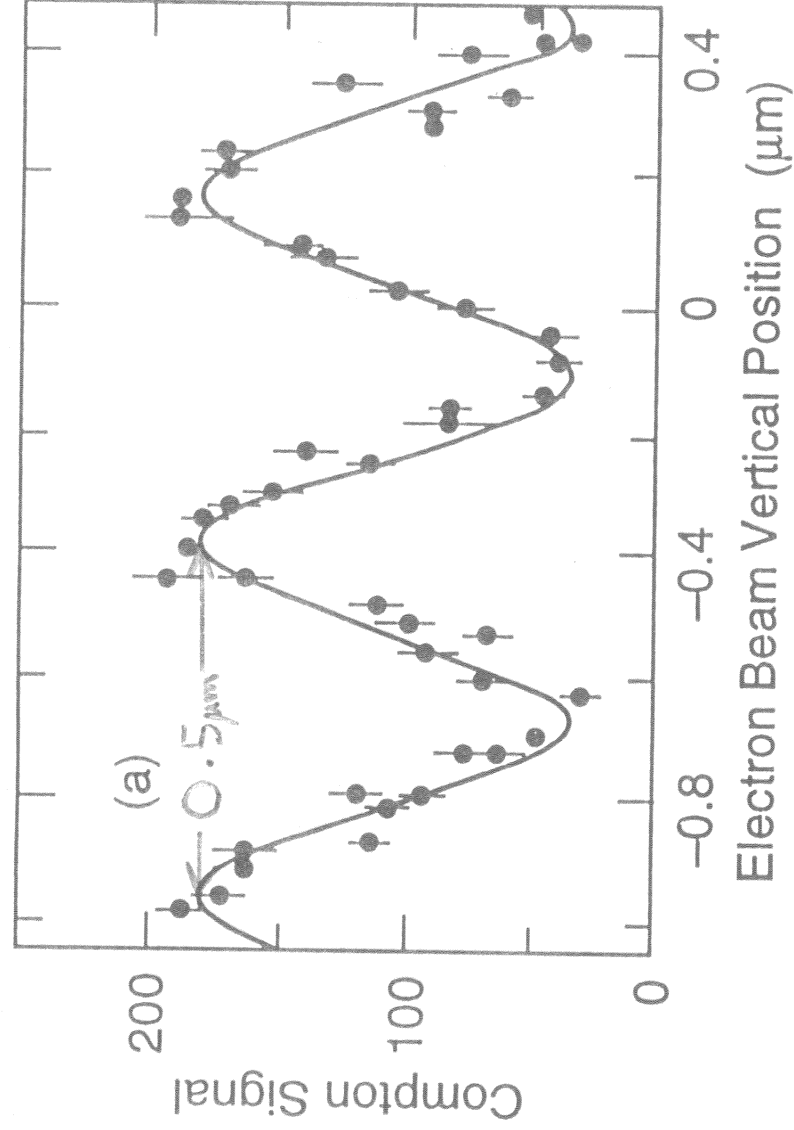
SLAC Two-mile Accelerator & FFTB



Laser Interferometer Table



FFTB Spot Size Measurement



1-95

7875A50

=> Beam demagnification $\times 320$

} routine
} @ SLC.

Test facility: Nakanishi (Nagoya)

ATF: ✓ within factor of 2

✓ 70 MV
✓ 35 MV

✓ 320 @ FFTB

PHYSICS DEMANDS AT A LINEAR COLLIDER

- C.M.: $200 \leq \sqrt{s} \leq 800$ GeV (and maybe at Z^0)
- Multijet final states with heavy-flavour jets

$$e^+e^- \rightarrow Z^0 H^0 \rightarrow f\bar{f} b\bar{b}$$

$$f\bar{f} c\bar{c}$$

$$f\bar{f} \tau^+\tau^-$$

$$e^+e^- \rightarrow t\bar{t} \rightarrow bW^+ \bar{b}W^-$$

$$e^+e^- \rightarrow t\bar{t} H^0 \rightarrow bW^+ \bar{b}W^- b\bar{b}$$

$$e^+e^- \rightarrow h^0 A^0 \rightarrow t\bar{t} t\bar{t}$$

$$e^+e^- \rightarrow \tilde{t}\tilde{t} \rightarrow \chi^0_c \tilde{\chi}^0 \bar{c}$$

- Jet energies: $50 \rightarrow 200$ GeV
- Track momenta ($\sqrt{s}=500$ GeV): $\langle p \rangle \sim 2$ GeV/ c
- Missing energy signatures, *eg.* SUSY:

$$e^+e^- \rightarrow \tilde{l}^+ \tilde{l}^- \quad \text{or} \quad \tilde{q} \tilde{q}$$

$$e^+e^- \rightarrow \tilde{\chi}^+ \tilde{\chi}^- \quad \text{or} \quad \tilde{\chi}^0 \tilde{\chi}^0$$

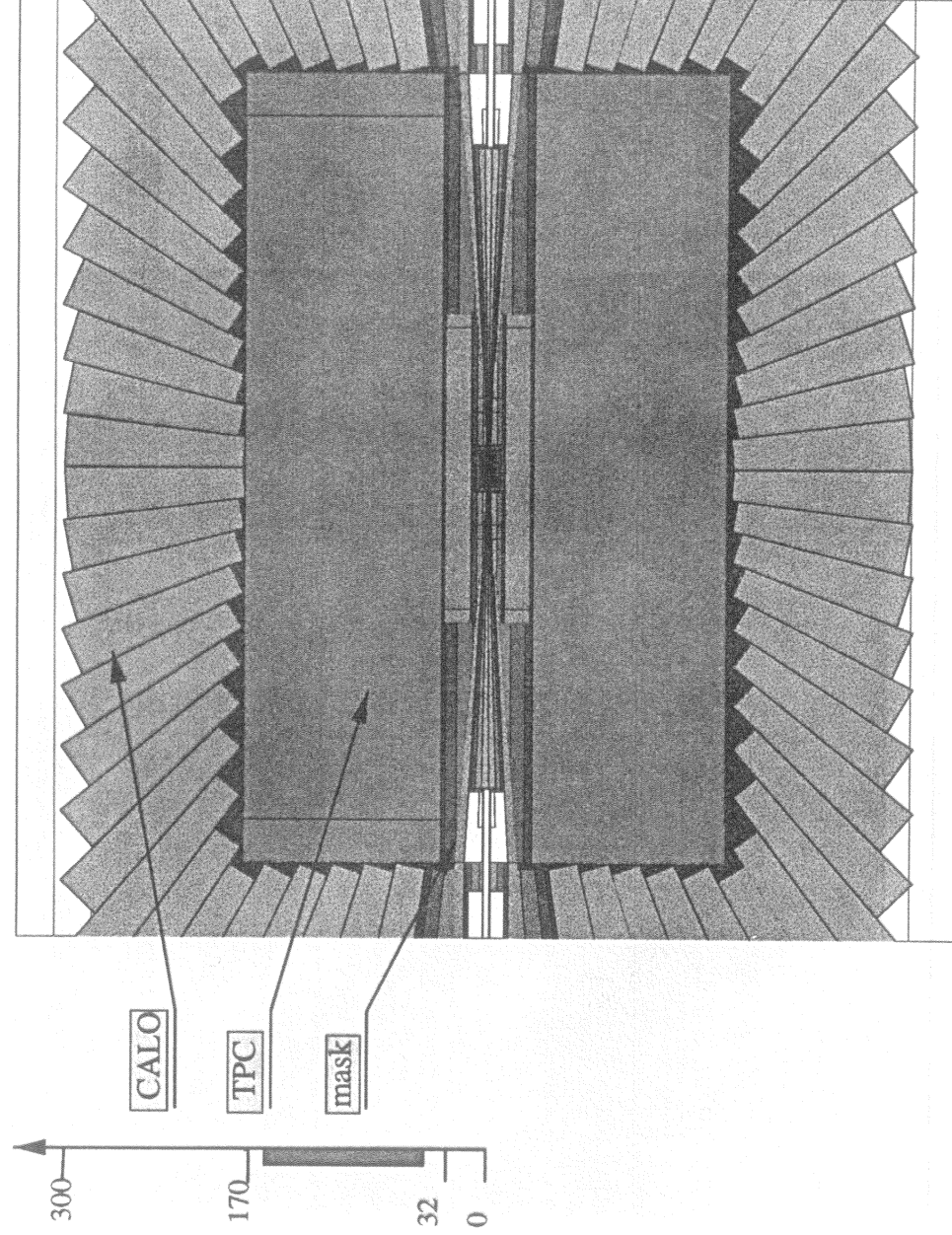
- Or other exotic scenarios:

$$e^+e^- \rightarrow \tilde{\chi}^0 \tilde{\chi}^0 \rightarrow \tilde{G} \gamma \tilde{G} \gamma \quad (\text{GMSB})$$

$$e^+e^- \rightarrow G \gamma \quad (\text{extra compact dimensions})$$

A Detector for TESLA

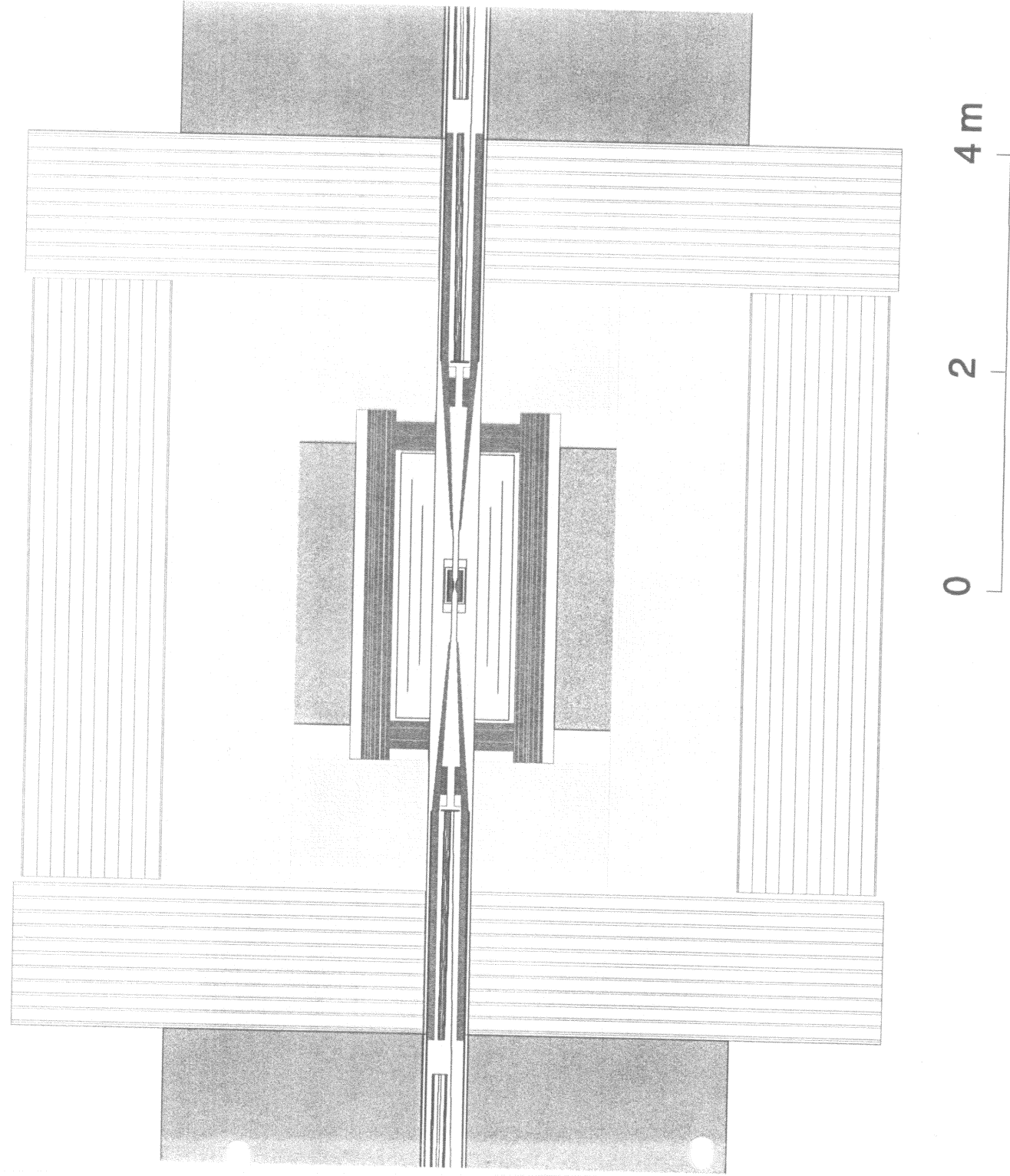
- General concept: Large detector, gaseous tracking, large acceptance
- main tracking components:
 - high precision vertex detector (4-5 layers)
 - large TPC tracking chamber



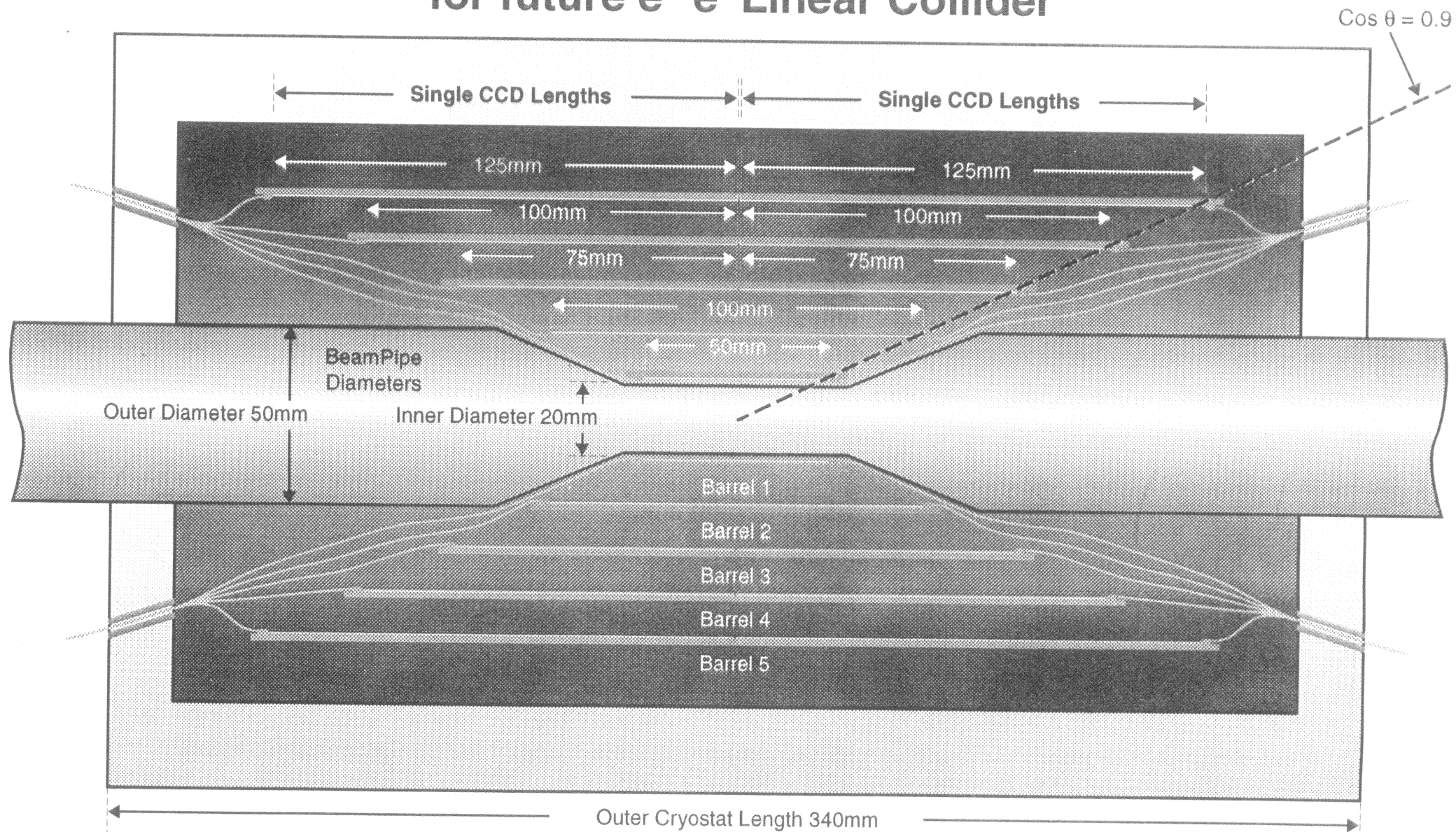
- configuration:

$$\begin{aligned}
 z &= \pm 250 \text{ cm} \\
 R_i &= 32 \text{ cm} \\
 R_o &= 170 \text{ cm} \\
 N_{hit} &= 118 \\
 \text{Gas} &= \text{Ar/CH}_4 \text{ 90-10}
 \end{aligned}$$

LCD Small Detector in GEANT3



Suggested layout of Vertex Detector for future $e^+ e^-$ Linear Collider



Chris Damerell
Rutherford Appleton Laboratory
May 1996

LC STATUS: JAPAN

- **Strong collaboration with SLAC:**

International Study Group

Joint development of X-band technology

- **Monbusho + STA merged January 2001**
- **First priority is Japan Hadron Facility:**
 - \$1.9B project
 - construction start FY01 (?)
 - 5-year construction period
- **Small accelerator community, based at KEK**

⇒ Earliest start on JLC $\geq$ 2006

Need technical contributions from abroad

LC STATUS: EUROPE

- LHC under construction:
funding $\rightarrow 0$ in 2008
energy/lumi upgrades under discussion
US contributing $\sim \$600\text{M}$
- CLIC R&D supported: possible post-LHC project
- TESLA TDR submitted March 2001
- TESLA planning permission obtained
- TESLA environmental impact study in progress
- 2002: Recommendation from German Govt.

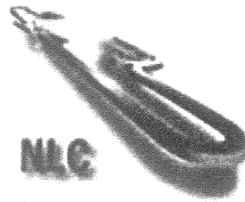
$\Rightarrow$ TESLA probably 'approved' as international project



Figure 1.2.3: The TESLA site North-West of the DESY laboratory.

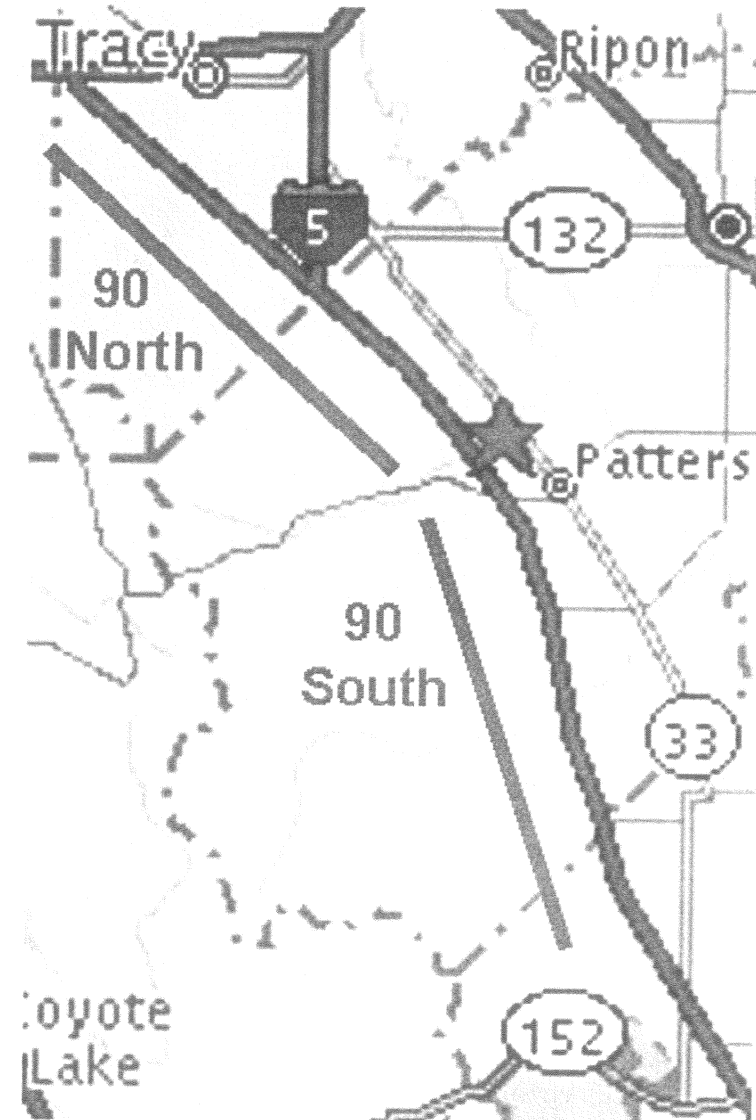
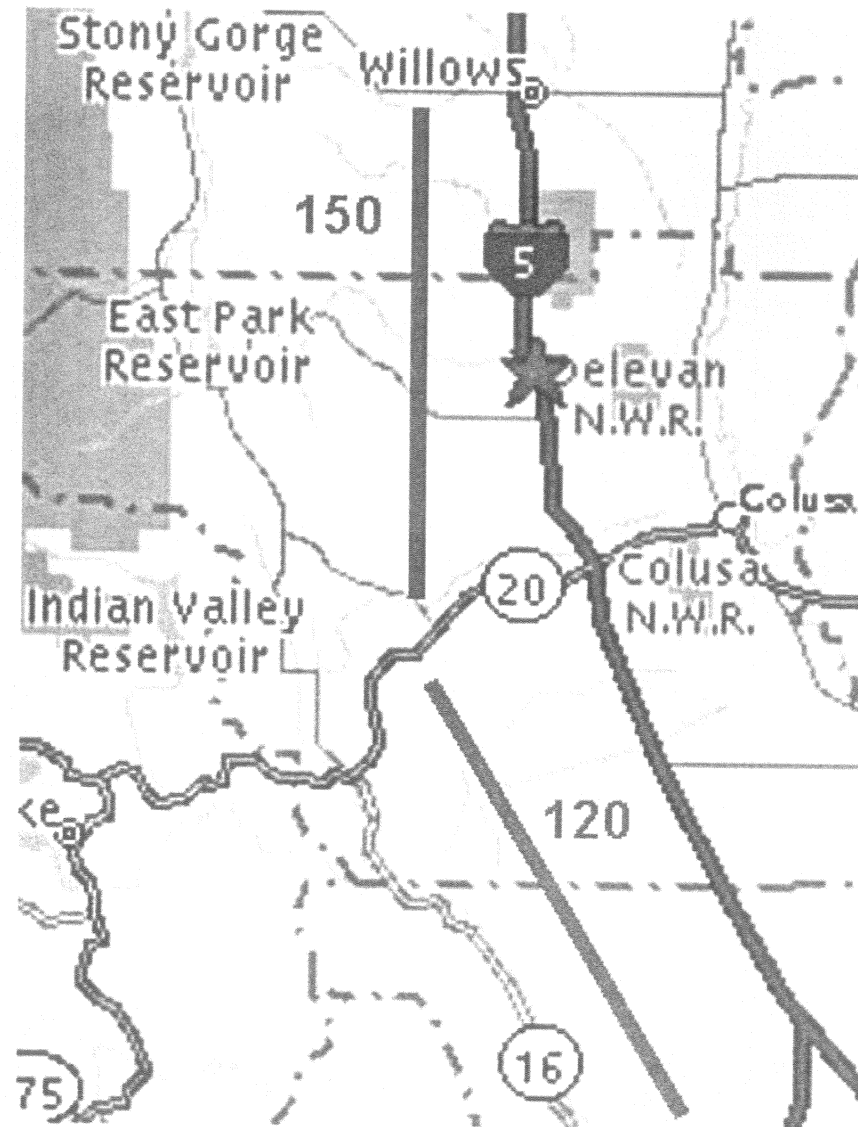
LC STATUS: U.S.

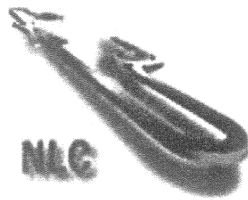
- Strong domestic programme until c. 2006:
No major domestic facility approved for LHC era
 - Gilman 'white paper' December 2000
 - Snowmass meeting ('think tank') July 2001
 - HEPAP subpanel to report late 2001
 - SLAC, FNAL, LBL, LLNL: US NLC Consortium
NLC R&D \$19M this FY
 - New administration January 2001:
O(\$10¹²) budget surplus
- ⇒ Community decision on NLC MUST be taken
in next year



California Sites

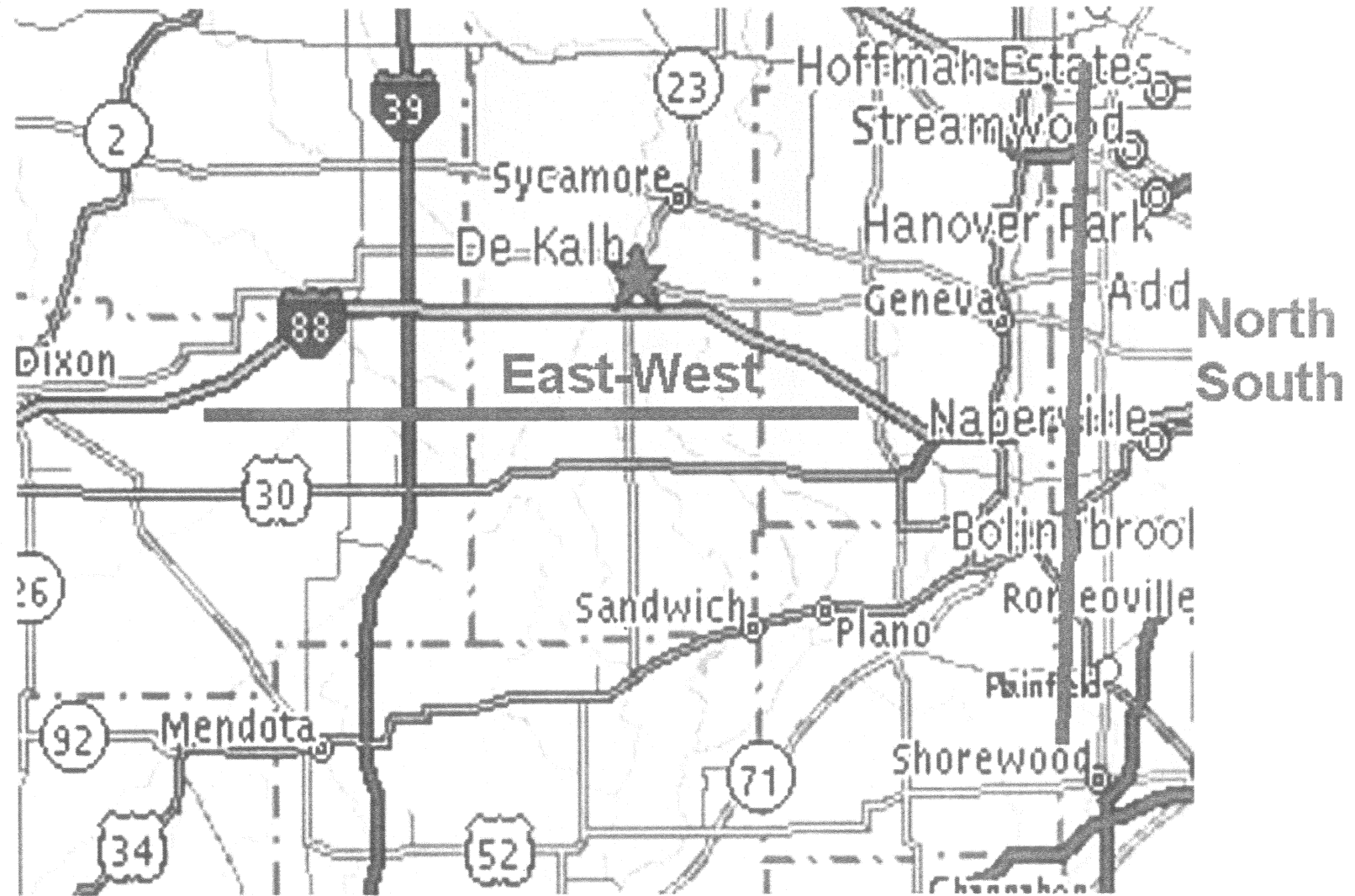
Next Linear Collider





Illinois Sites

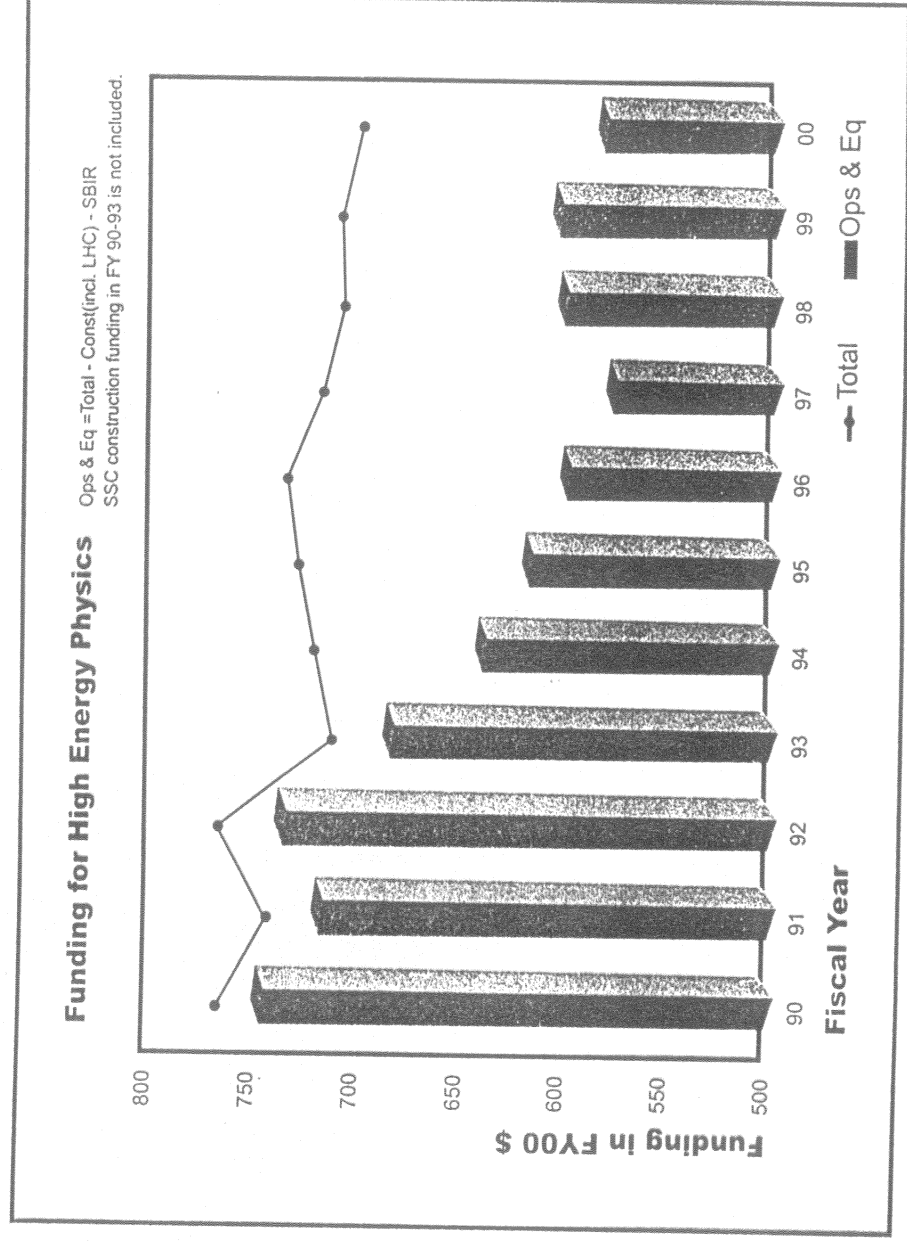
Next Linear Collider



U.S. Science Funding

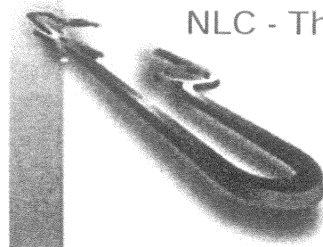
Science funding by agency, in \$ millions

Agency	FY 1993	FY 2000	Change	Δ (Constant \$)
NIH	10,335	17,813	+72%	+46%
NSF	2,750	3,897	+42%	+19%
NASA Science	4,058	4,895	+21%	+10%
DOE Science	3,066	2,788	-10%	-24%



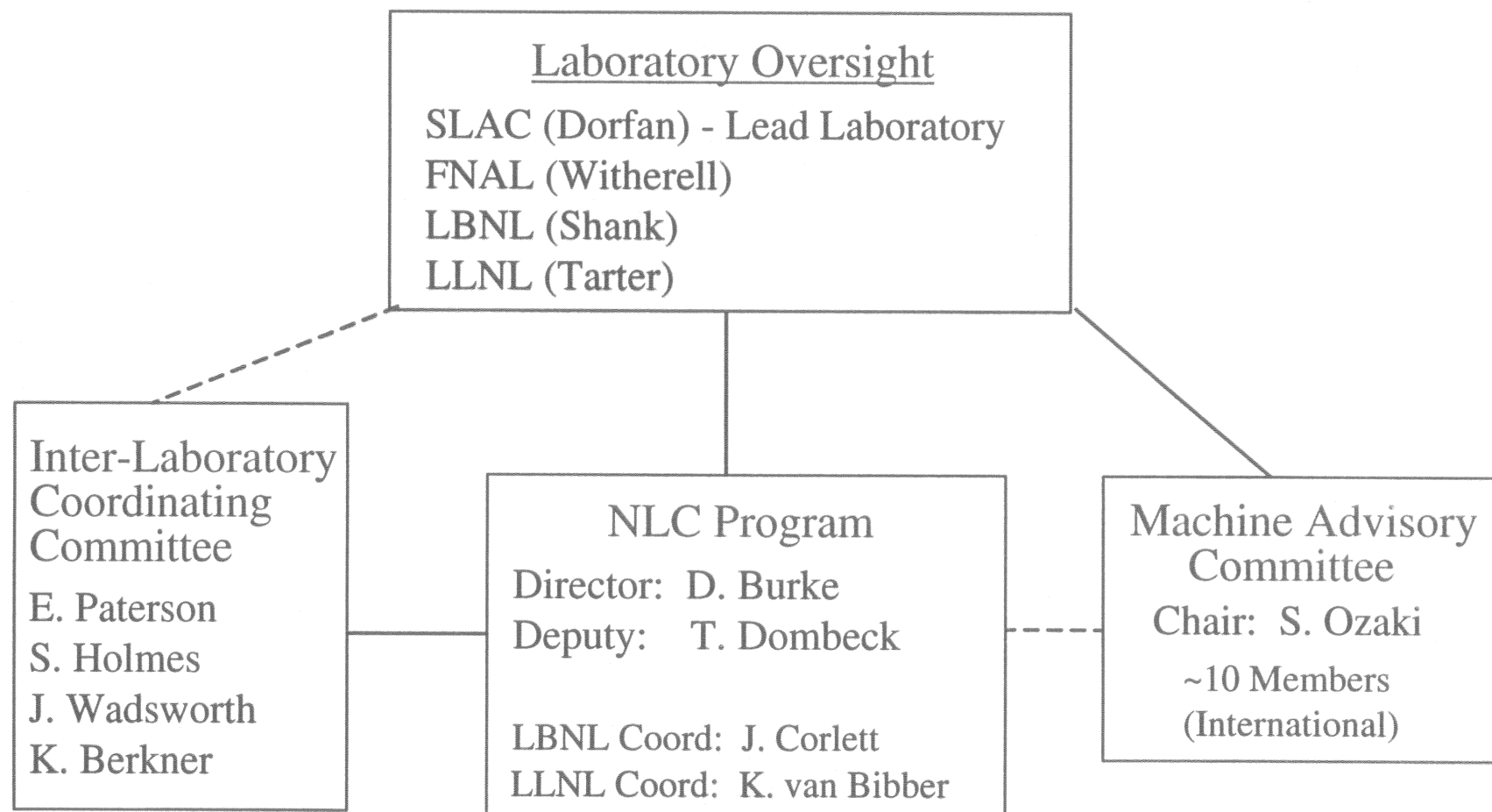
Current NLC Timetable

- HEPAP recommendation and Lehman Review
- Winter 2002: CD-0 'Approve mission need'
- Construction of Engineering Test Facility at FNAL:
400m section of RF system
Preparation of CDR
- HEPAP recommendation and Lehman Review
- Winter 2004: CD-1 'Approve prelim. baseline range'
- ????: CD-2 'Approve performance baseline'
- ????: CD-3 'Approve start of construction'
- ????: CD-4 'Approve performance baseline'



U.S. NLC Collaboration

March 2000



LC CRYSTAL BALL

- **World community planning getting going**

Aug. 1999: ICFA statement:

To explore and characterise fully the new physics ... will require the LHC plus an e^+e^- collider in the TeV energy range ... We believe that an e^+e^- collider optimised for the new physics should be built in a timely way with international participation.

- **Regional reviews under way:**

ECFA, HEPAP, JHEP committees on future

Global planning document for particle physics?

- **Inter-regional coordination starting via ICFA:**

Review panel to assess machine designs?

‘Global Accelerator Network’ to engage all labs.

Major lab. directors cooperating

⇒ **CONSENSUS:** aim for construction start ≤ 2005 ;
physics 2010

SUMMARY

- **Compelling physics case for e^+e^- collider:**
 $300 \leq \sqrt{s} \leq 1500$ GeV
- 300-500 GeV collider $\Rightarrow$ Higgs + top factory
- **1 - 1.5 TeV collider $\equiv$ LHC for ‘discovery potential’**
High signal/background
Clean experimental environment
Systematic energy scan
Polarised beam(s)
Precision VXD very close to IP
 $\Rightarrow$ complementary approach to EWSB studies
- **TESLA TDR presented Spring 2001**
U.S. Snowmass (July 2001) very important
- **Construction start $\geq$ 2003**
- **First physics $\geq$ 2010**