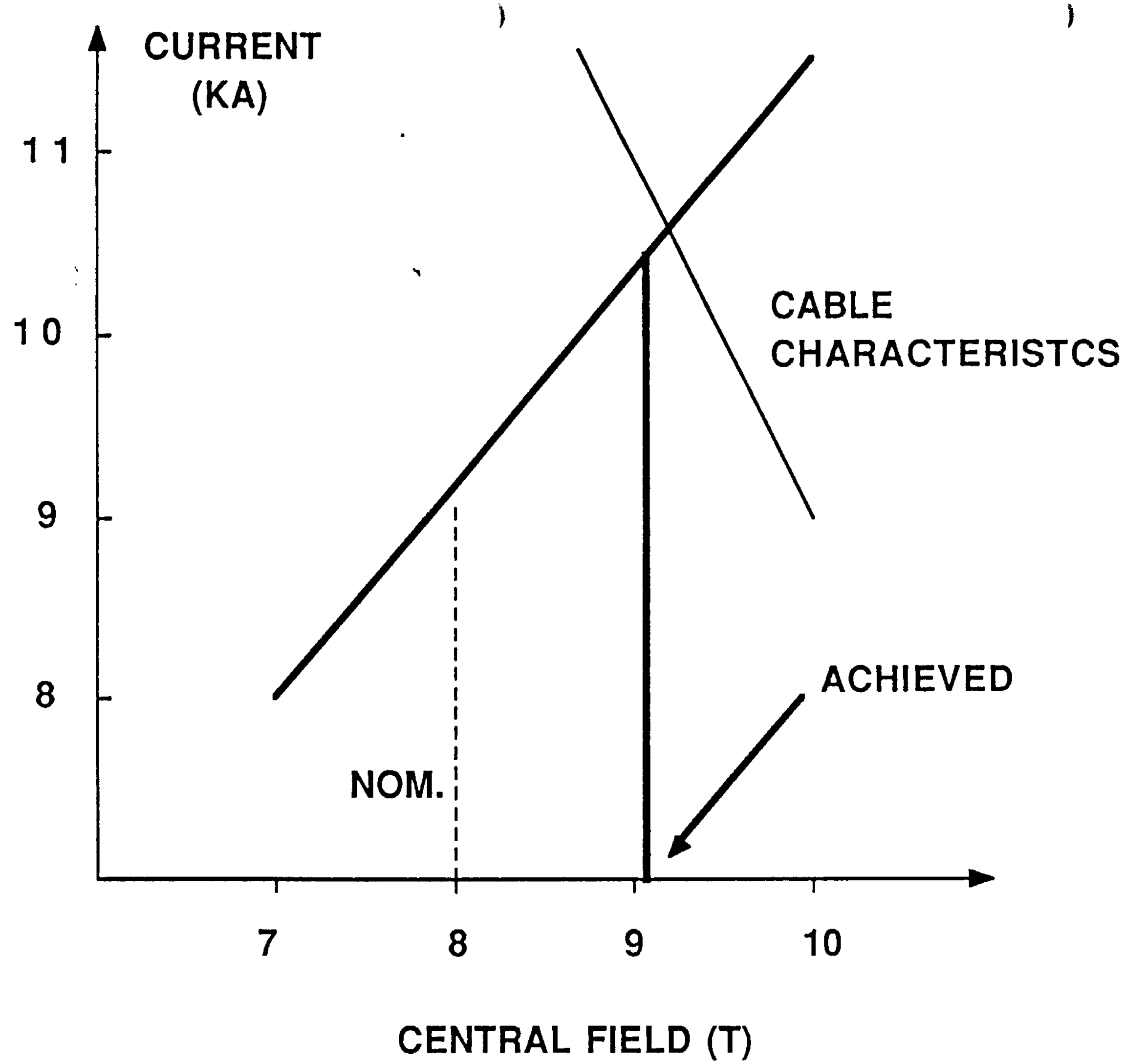
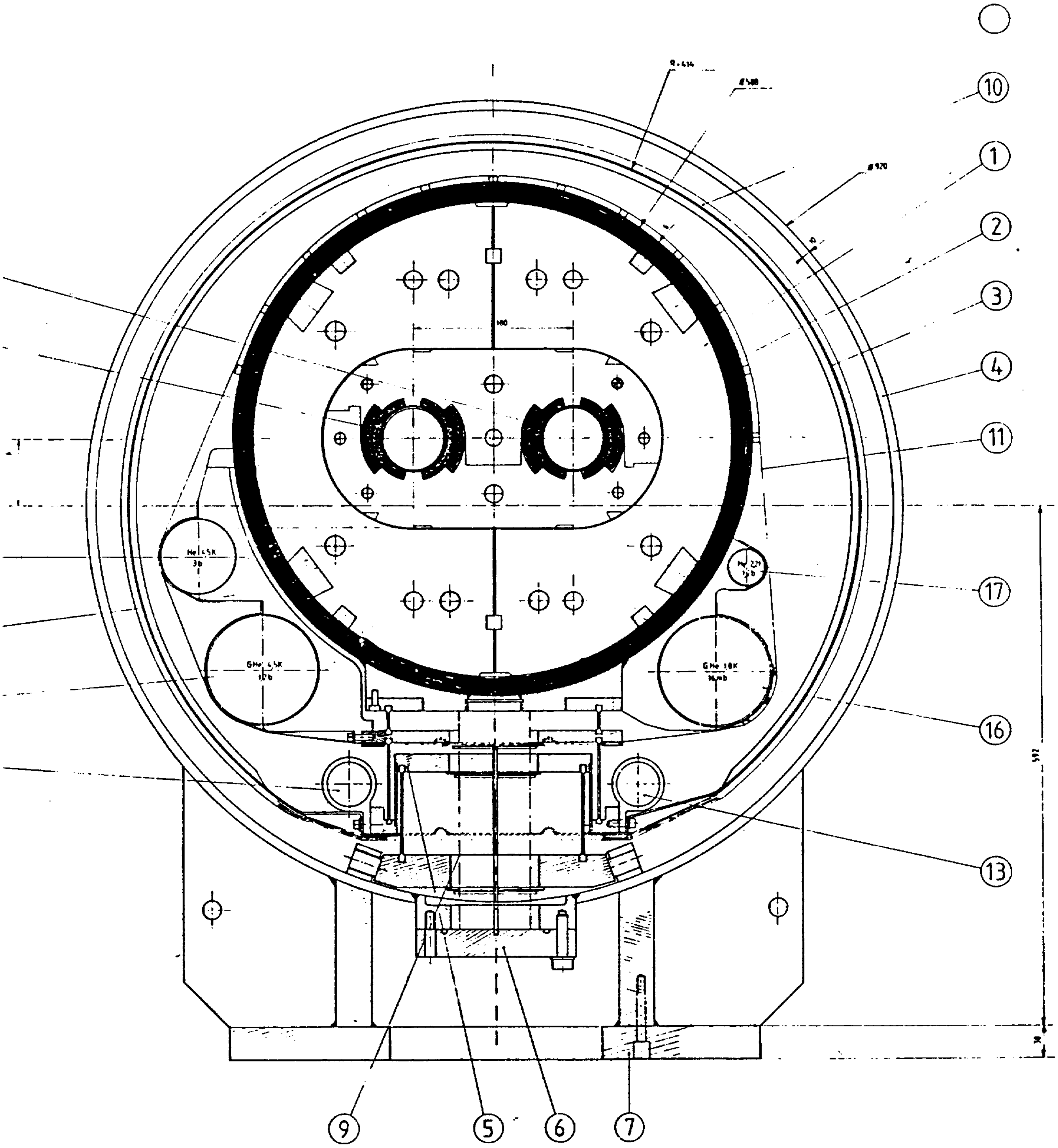
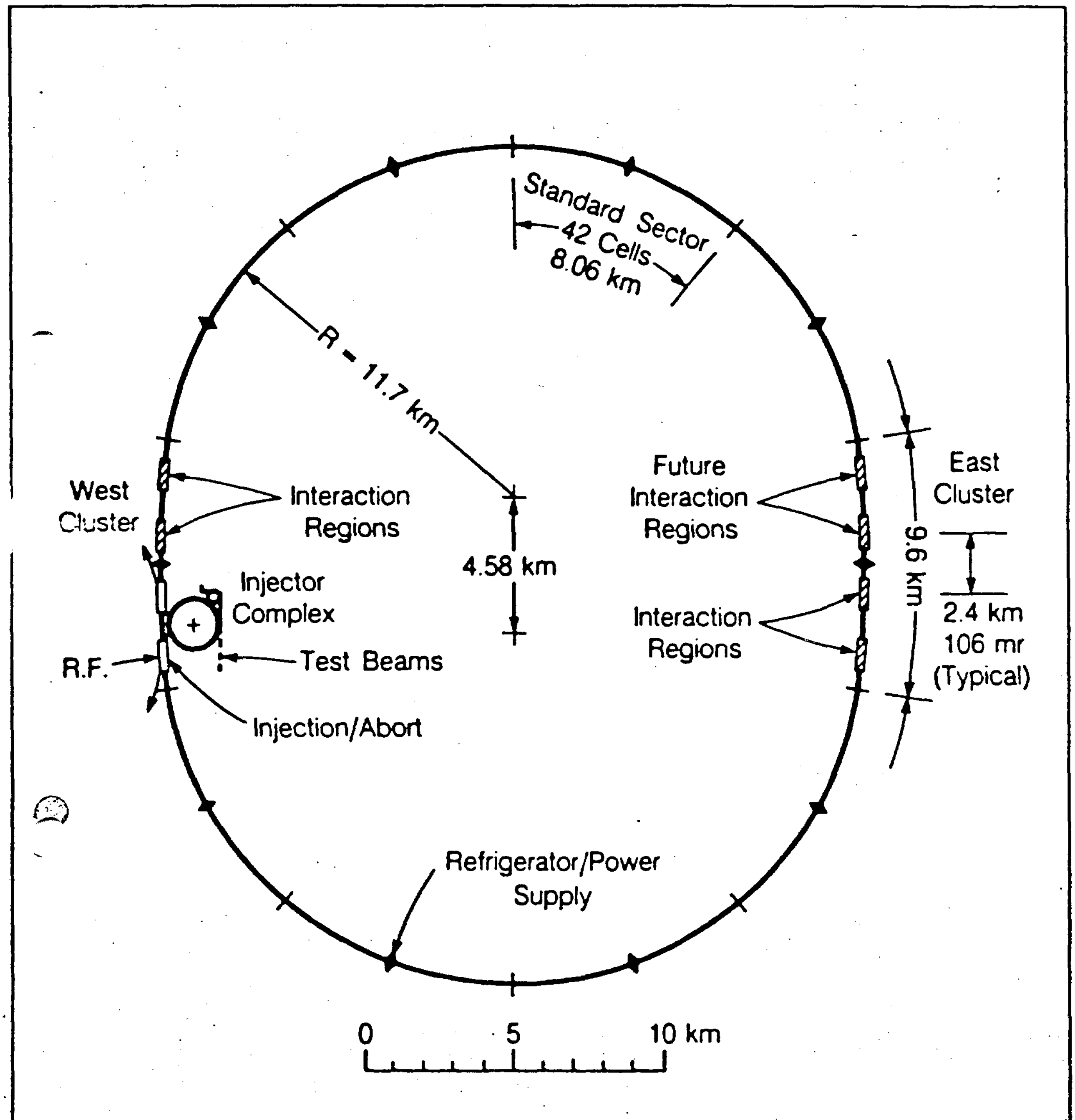


RESULT OF FIRST LHC MODEL



TWIN APERTURE DIPOLE
(HERA COILS)



Standard Sector
42 Cells
8.06 km
R = 11.7 km
West Cluster
Interaction Regions
4.58 km
Injector Complex
R.F.
Test Beams
Injection/Abort
Future Interaction Regions
Interaction Regions
East Cluster
9.6 km
2.4 km
106 mr
(Typical)
Refrigerator/Power Supply
0
5
10 km

SSC

SSC - Reference Design Study Groups Daft II, May 8, '84

Table 1-1
Primary SSC Design Objectives

Maximum beam energy [TeV]		20	
Injection energy [TeV]		1	
Maximum luminosity [$cm^{-2}sec^{-1}$]		10^{33}	
Maximum number of interactions per bunch crossing (at max. luminosity)		10	
Number of interaction regions		6 (4 initially developed)	
Field [T]	6.5	5	3
Circumference [km]	90	113	164

Magnets for SSC:

Similar to HERA (see earlier diagrs.)

Some differences:

- Less stabilising copper in filaments.
  (cause of some training and not quite reaching short sample field?)
- Thinner filaments (to reduce need for correction of persistent currents)
  (Reason for erratic behaviour?)
- Longer magnets (~ 20 m versus 9 m)
- End clamps?
- Stainless steel collars
- Higher ~~the~~ operating field (6.7 T)

More development needed to reach design goal with reasonable safety.

Eloisatron

Eurasiatic Long Intersecting Storage Accelerator

BLE 5.2 - SOME TENTATIVE PERFORMANCE PARAMETERS FOR ELOISATRON

Energy per beam	100 TeV at 10 T
Number of bunches	39600 per beam
β-value at interaction point	1.25 m
Normalized emittance	$0.75\pi \times 10^{-6}$ m
r.m.s. beam radius at inter. point	1.25×10^{-6} m
Circulating current	16.43 mA
Particles per bunch	2.56×10^{9}
Beam-beam tune shift (with 6 active crossings)	1.67×10^{-3}
Bunch spacing	25×10^{-9} s
Stored beam energy	1.623×10^{9} J
Luminosity	0.91×10^{33} $cm^{-2}s^{-1}$
Energy loss per turn due to synchrotron radiation	23.34 MeV
Radiated power (per beam)	385 kW
Power per unit length of one beam	1.89 W/m
Transverse em. damping time	1.2 h

TABLE 5.1 - LATTICE PARAMETERS

Length of period	200 m
Phase advance per period	π/3
Betatron wavelength	1200 m
Bending angle per normal period	4.7 mrad
Number of normal periods	< 1332
Number of quads per period	2
Effective length of each quad	13.6 m
Total nº of quadrupoles	2664
Maximum dipole field	10 T
Number of dipoles per normal period	12
Effective dipole length	13.1 m
Total nº of dipoles	15984
Bending radius	33356 m
Circumference	300 km

Magnet performance similar to the one of the LHC magnets. Smaller aperture. No need for "2 in 1" design.

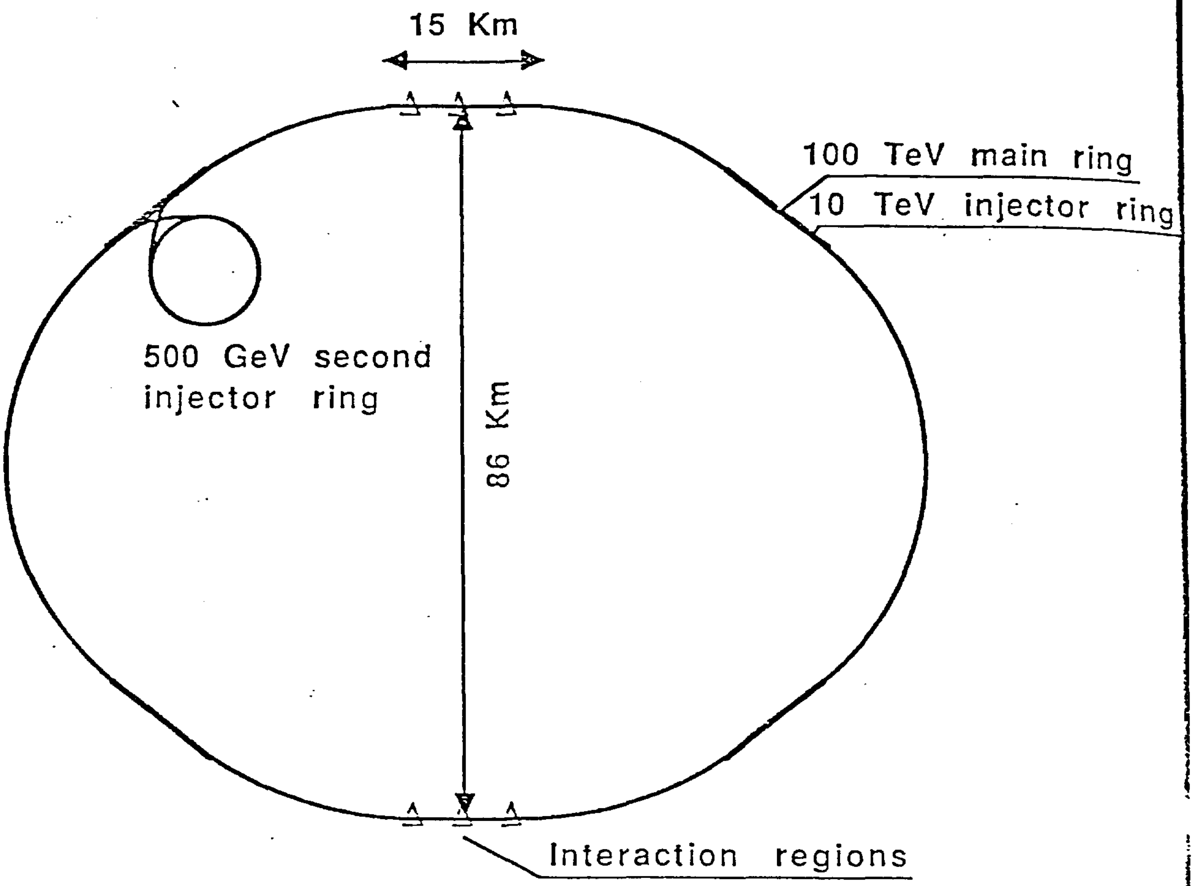


Fig. 5.1 - Possible ELOISATRON layout

This place for remarks on "warm" s. c.

- T_c > liquid nitrogen great advantage.
- Considerable research needed to establish mechanism behind this
- Can suitable materials be found? Or suitable magnets designs for materials available.
- Probably long engineering development Reminder: Technological developm. relatively slow.
- Vacuum

Conclusion on hadron colliders:

The technical knowledge now exist for the construction of any of the 3 proposed pp colliders in the 5-100 TeV range. (Technically ripe.)

- SSC waiting approval, not obvious
- LHC waiting to see if SSC goes soon, if not the thing for Europe to do.
- Eloisatron (probably) for somewhat later, unless funding can be justified for other reasons than basic research alone

Future e-colliders (3rd lecture)

Under construction

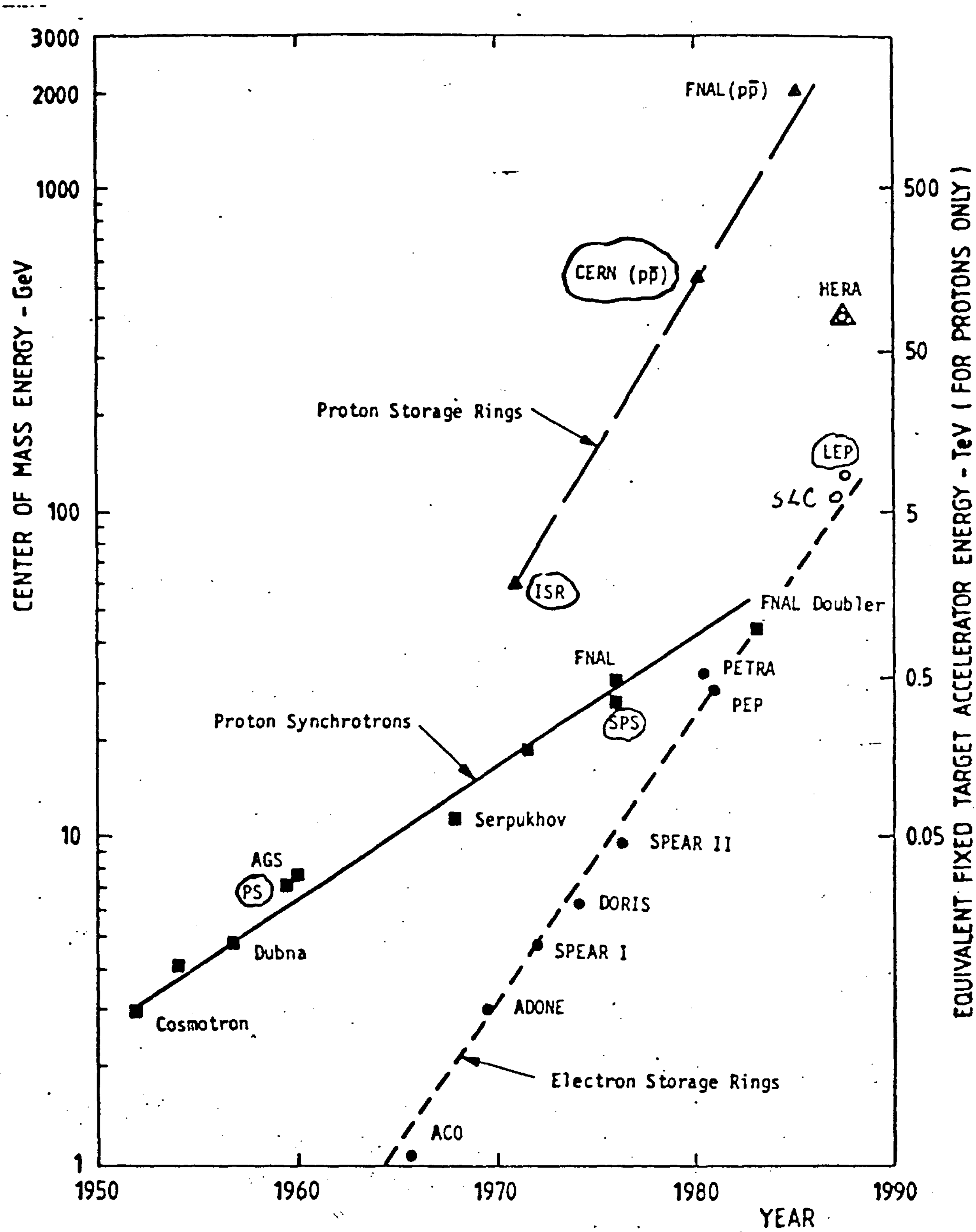
Back to modified Livingston

- SLC (for later under CLIC)
- HERA e-ring (back to pos. table of HERA)
- LEP

Speculations for the future:

Linear colliders

- SLC
- CLIC
- Others.



Livingston plot for fixed-target synchrotrons and colliders (c.m. energies)

Not complete in the respect that it contains only machines on or near the energy frontlines.

LEP

Magnets:

Steel laminations with
concrete inbetween.

LEP

Back to photo.

LEP well known here, and not for me to describe.

Many beautiful technical achievements made. Apologies.

Two points to single out in context of my talk:

— 1. Unusual magnet design (that may not point to future)

— 2. Developm. and constr. of s.c. cavities (that very likely points to future)

To go to ~100 GeV beam energy with no or little increase in r.f. power

r.f. power < beam power
r.f. power < ~~copper~~ ohmic losses (very much reduced with s.c.)

Why s.c. cavities for LEP and HERA?

$$P_{r.f.} = P_r + P_c$$

$$= \frac{I}{e}\frac{C\gamma^4}{\rho} + \left(\frac{k}{e}\right)^2 \frac{C^2\gamma^8}{\rho^2 Z_s L_c}$$

r.f. system with storage cavities help in LEP, but..

$\downarrow$ ~1.6 MW $\downarrow$ ~12 MW for LEP at 55 GeV

With the strong γ dependance P_c soon becomes prohibitive above say 60 GeV. s.c. cavities lifts this limit to around 100 GeV, when also P_r starts becoming prohibitive.

In the e-ring of HERA purpose ~27 GeV $\longrightarrow$ ~35 GeV

Important for polarisation.

There are also other advantages of s.c. r.f., e.g. higher acc. fields ~~in~~ at frequencies used in these machines.

S. C. cavities:

Again a very long and tedious development.

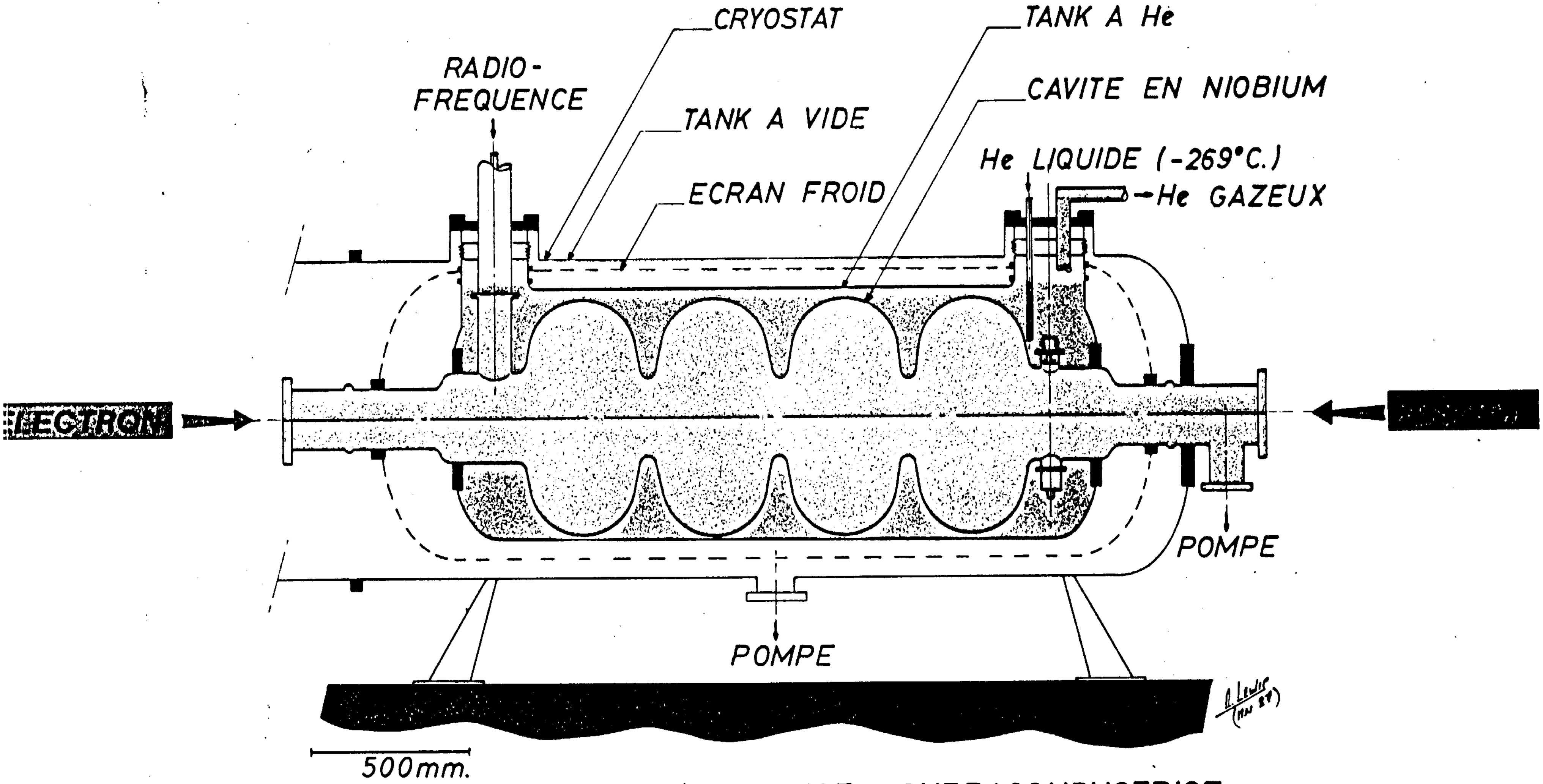
SLAC (in the '60-s)
Cornel
Karlsruhe / Frankfurt

Karlsruhe / CERN on separators ~3 GHz, 5000 h.
CERN → LEP II
DESY → HERA > 30 GeV
Cornell / CEBAF

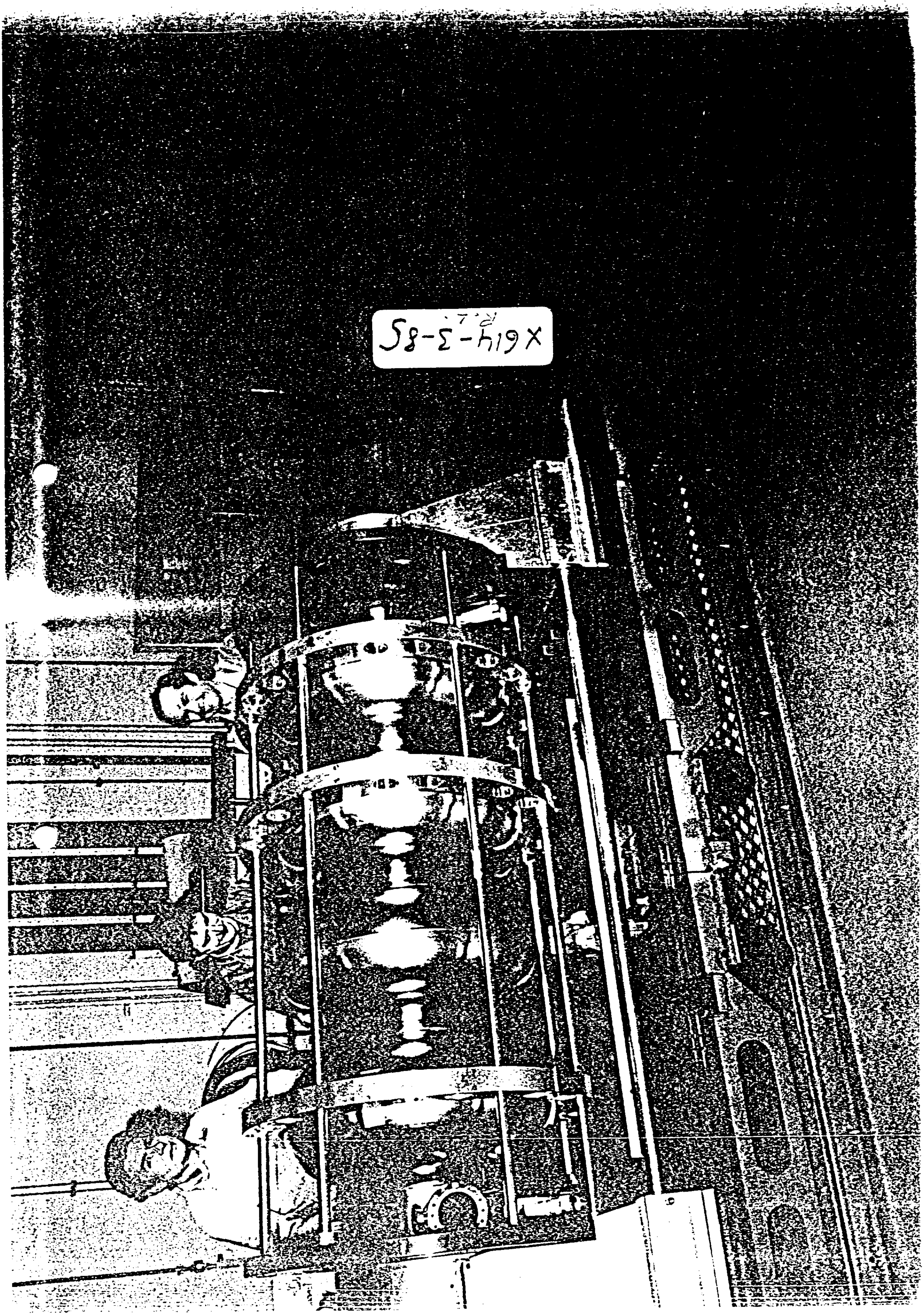
Example: LEP II 350 MHz

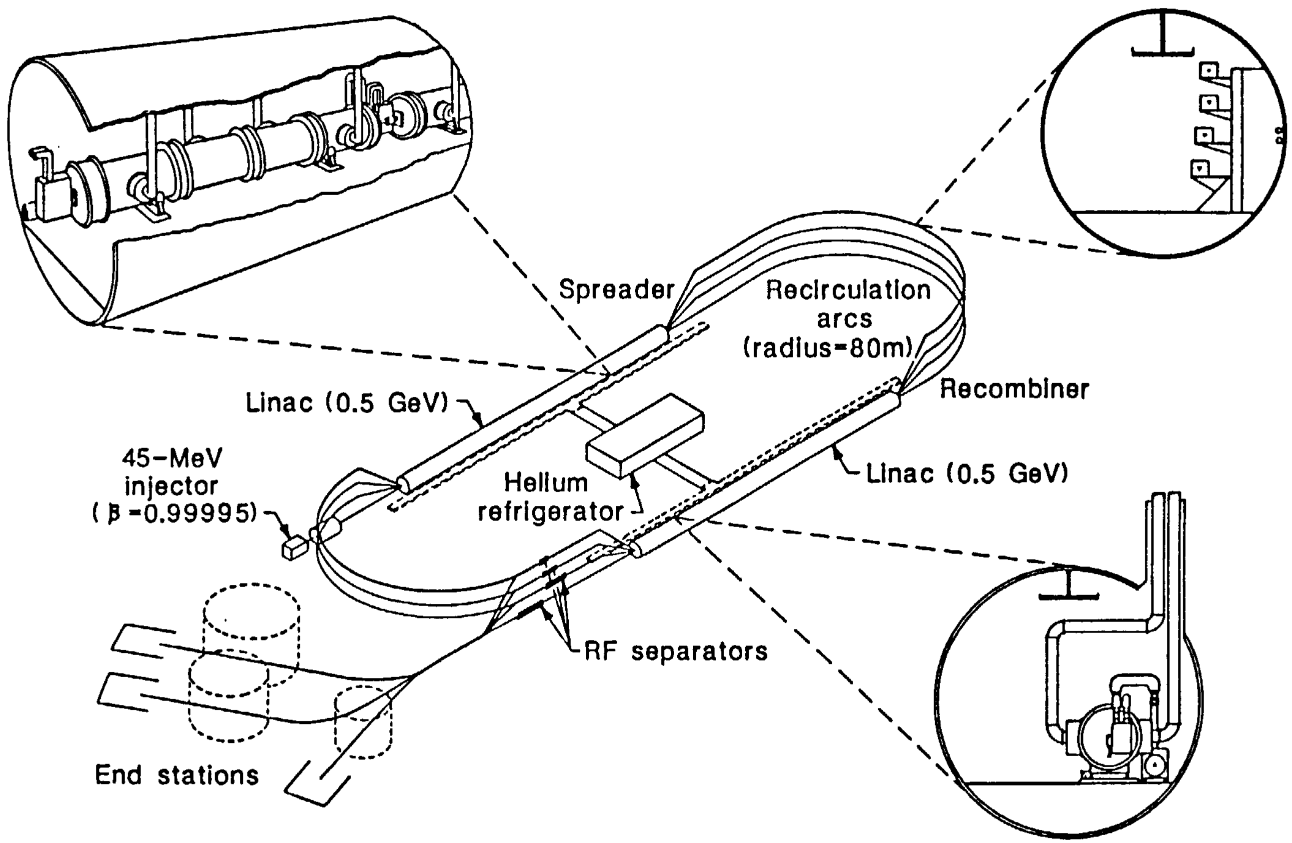
HERA similar (for time being) but 500 MHz

CEBAF biggest project for time being.



SCHEMA D'UNE CAVITE SUPRACONDUCTRICE
et D'UN MODULE DE CRYOSTAT


X614-3-85



Layout of the CEBAF 4-GeV superconducting recirculating linac, Newport News, Virginia.

S.C. cavities may be a crucial development for the future (see later)

Warm s.c. layers for cavities? Even more attractive than for magnets!!

LEP (at 2×100 GeV) last circular
e^+e^- collider

due to syn. rad.

↓ Go to larger ρ.
Limit $\rho \to \infty$, i.e. linear collider.

CLIC

Why second project to be considered?

1. Present approaches cumbersome, i.e. look for new ones.
2. Time has come not to duplicate → complementarity, SSC or LHC ⟷ another approach on other side. !
3. e^+e^- complementary to pp, even more interesting.

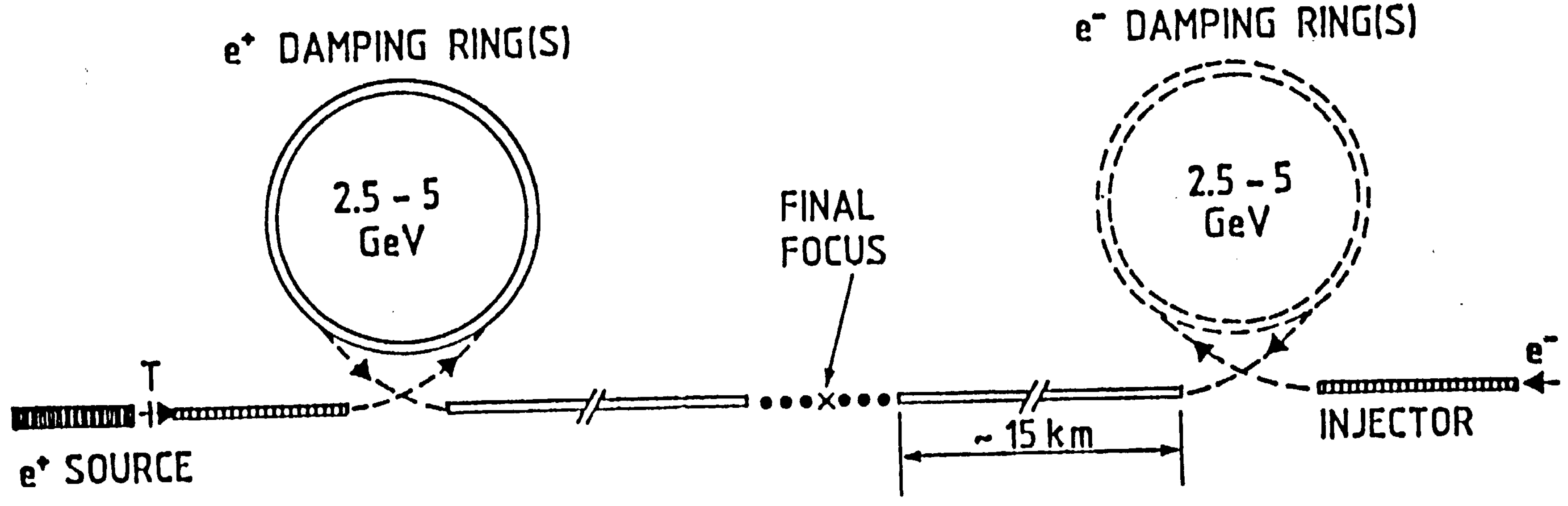
Linear Colliders
(CLIC for CERN Linear Collider)

Main reasons:

a) electrons are constituents, therefore all accelerator energy available. $E_{e^+e^-}$ equivalent to $\sim \frac{1}{10} E_{pp}$.
At first sight attractive energy wise.

b) Cleaner interactions
(Necessarily true?)

c) Complementarity with other projects
LEP compl. to Isabelle (cancelled)
CLIC " " SSC
or US Lin. Col. " " LHC



The concept of linear colliders

Some General Considerations.

$$\text{Luminosity} = \frac{\bar{f}_b N^2}{4\pi \sigma_x \sigma_y} H_D$$

Particles per bunch must be high
Average bunch rep. freq. must be high
Beam size must be small
requiring damping to very small emittances
and very sophisticated final focus
However: electromagnetic disruption (pinch)
beam radiation (classical, or quantum

Can a ballance be found so that the power problems can be handled?

Efficiency
Peak power
Average power

} All difficult technical problems

Various approaches to linear colliders

Some years ago it was felt that the main problem would be to create very high accelerating fields. This certainly called for rather exotic ideas, some of which died quickly, some still stay in the race with varying degrees of promises.

We have scrutinised some of the more promising ones, and I will list those, with a few comments

After this I will give some more detailed comments and parameters for the one alternative we consider the most promising one, at least on a relatively short time scale.

SLAC Linear Collider (SLC)

$E = 2 \times 50$ GeV

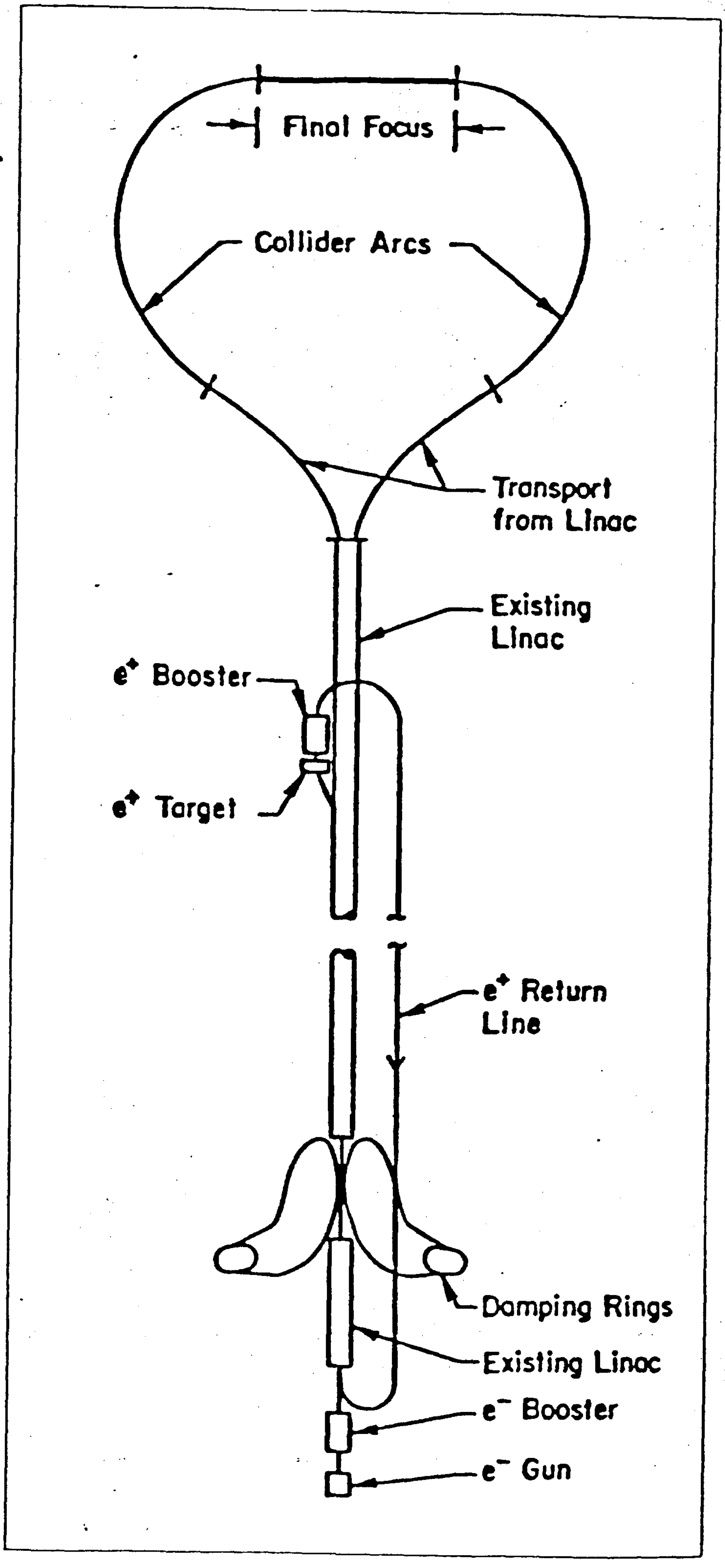
$L = 6 \times 10^{30}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (long-term aim)

$\sigma_r = 1.4\ \mu\mathrm{m}$

$\sigma_\ell = 1$ mm

$f = 3$ GHz

$f_{rep} = 180$ Hz



3. Possible Methods and Techniques.

3.1 Normal-conducting Accelerating Structures

(W. Schnell et al)

3.2 Normal-conducting accelerating structures powered by superconducting drive structures.

(Schnell, Amaldi et al.)

3.3 Superconducting Accelerating Structures.

(Amaldi, Lengeler, Piel.

3.4 Structures excited by optoelectric switches

(Switched Power)
(W. Willis)

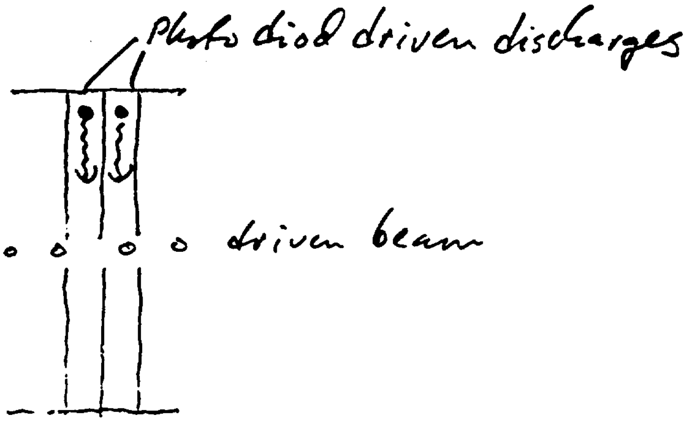
3.5 Wakefield acceleration (Voss, Weiland)

3.6 Plasma wakefields. (Chen, Huff, Dawson,) van der Meer

3.7 Plasma beat-wave acceleration. (UCLA

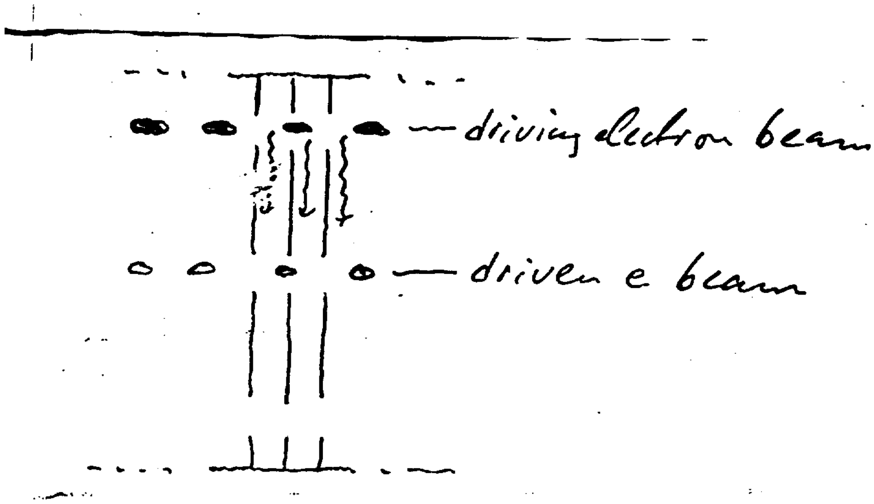
3.8 Ferroelectric [illegible]

W. W.



Optoelectric switches for acceleration

V. 2 W.



Wake field acceleration

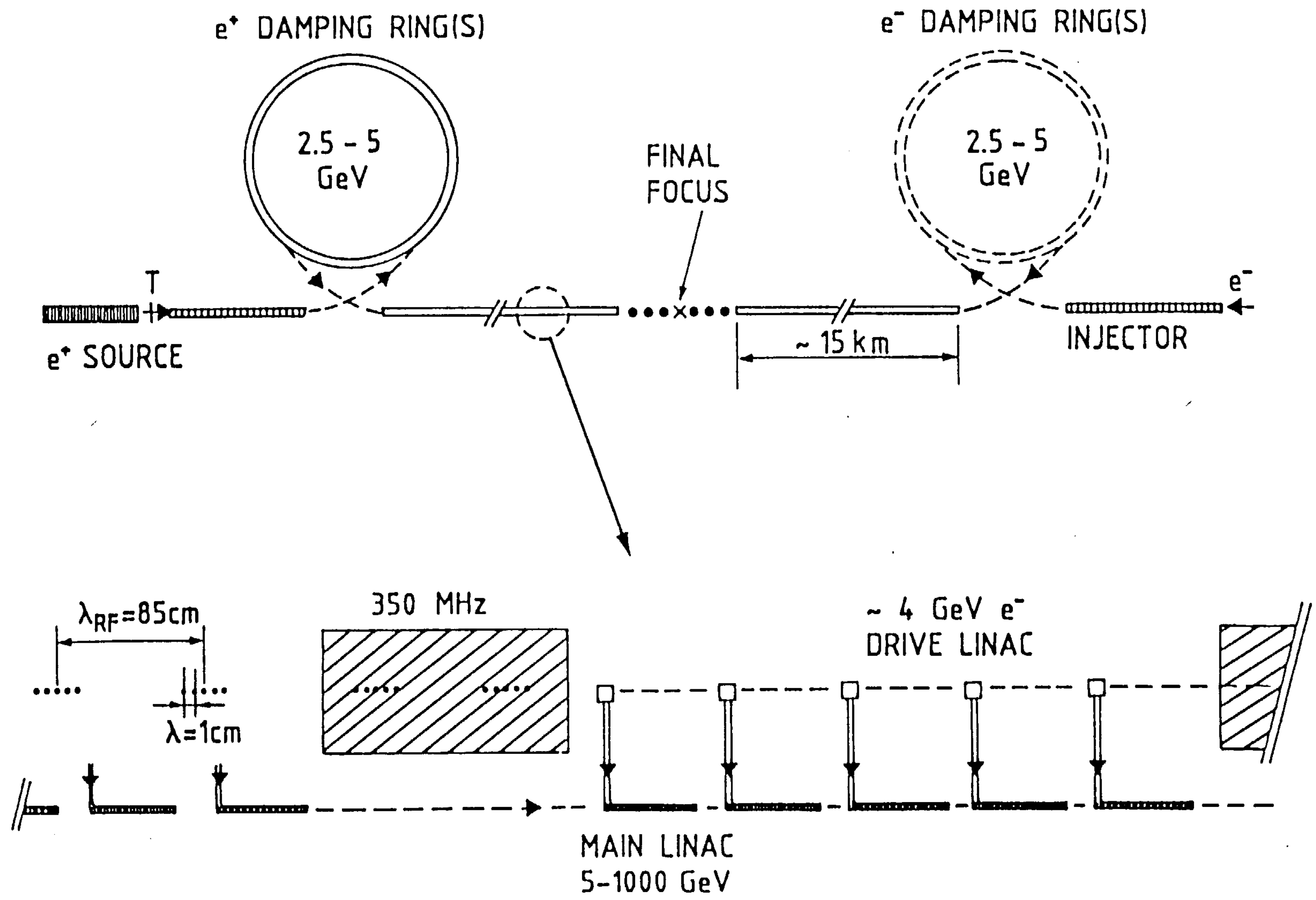
Classical "room temperature" RF driven linac. (W. Schnell)

- Breakdown
- Average power dissipation
- Peak power
- Wakefields (other than fundamental)

Desirable:

$\gtrsim$ 100 MV/m for 2×1 TeV e^+e^-

- Basic constraints (Lawson and others)
→ - Typical parameters
- Accelerating structures
- The peak-power problem
- Two-beam and two-stage RF schemes

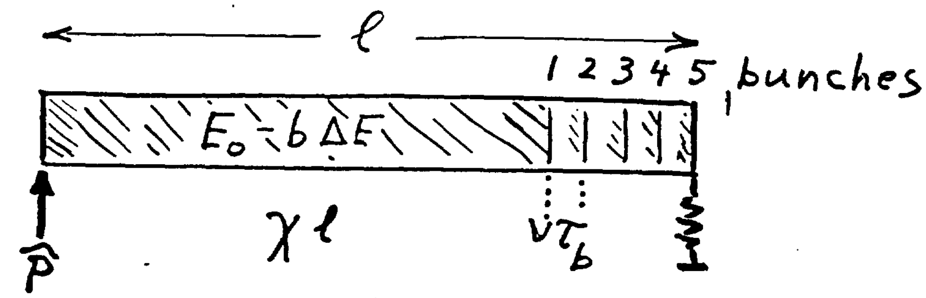


Schematic representation of a linear collider complex. In practice the positron source will make use of either the accelerated or the spent bunches. The electron damping ring system will probably not be needed, because low-emittance sources are now available and, for this reason, is dashed in the figure. The lower part of the figure represents the two-stage accelerator proposed by W. Schnell, which uses superconducting cavities at 350 MHz (LEP 200) to power the drive beam

		Old CLIC parameters (corrected for $a/\lambda=0.2$)	Proposed new CLIC parameters	SLAC TeV Collider para-meters [4]	
Energy	eU	1.0	1.0	0.5	TeV
Luminosity	L	1.1×10^{33}	1.1×10^{33}	1.7×10^{33} *	cm^2s^{-1}
Accelerating Gradient	E_0	80	80	186	MV/m
Final Focus Aspect Ratio	R	1	5	180	
Final Focus Beam Height	σ_y	65	12	1.3	nm
Fractional Energy Loss by Beam Radiation	δ	0.19	0.27	0.33	
Fractional Average Critical Energy	T	0.28	0.71	1.8	
Pinch Enhancement	$H_xH_y=H_0$	3.5	2.37	2.37	
Repetition Rate	f	5.8	1.69	0.1	kHz
Number of Bunches per Pulse		1	1	1	
Bunch Population	N	0.54	0.50	1.8	$\times10^{10}$
Beam Power	P_b	5	1.35	0.144	MW
Energy extraction	η	5.3	5.0	1.2	%
Iris Aperture over Wavelength	a/λ	0.2	0.2	0.2	
Shunt Impedance over Q per Unit Length	r'	28	28	11	kΩ/m
Fill Efficiency	η_τ	0.78	0.78	0.78	
RF Frequency	$\omega/2\pi$	29	29	11.4	GHz
RF Power (average)	P_{RF}	120	35	18	MW
Bunch Length	σ_z	500	200	40	μm
Disruption	D	0.91	3.3	14	
Vertical Emittance (normalized)	ϵ_{ny}	2.8×10^{-6}	10^{-6}	3.5×10^{-8}	rad m
Emittance Ratio	$\epsilon_{nx}/\epsilon_{ny}$	1	3 (say)	100	
Vertical Amplitude Function	β^*_y	3000	282	47	μm
Ratio of Amplitude Functions	β^*_x/β^*_y	1	8.3	320	
Peak power per unit length $\hat{P}_L/L$		96	9		MW/m

(If) multibunching were possible (longit. and transverse wakes?, final focus?); try to use it for increasing luminosity of given linac at given RF power.

Each bunch extracts fraction η of stored engy (as limited by ΔE within bunch). But b bunche extract $b\eta$ and average accel. voltage is restored from one bunch to next to avoid bunch to bunch spread.



$\chi \sim 80\%$ (say)

first bunch when wavefront at $\chi\ell$ sees $E_0\chi\ell$
(20% sacrifice in energy)
last bunch passes when structure is full

$\tau_b = \tau\eta/2$ between bunches so they all see $E_0\chi\ell$

$$\frac{P_b}{\langle P_{RF}\rangle} = (b)\eta g^2 , \quad (b) = 1 + 2(1-\chi)/\eta$$

might give factor 6 (say) increase of luminosity for only 20% (say) sacrifice in energy in a given linac   Tolerances?!

W. Sd. 18

2.5 to 5.0 TW total peak power !

$\hat{P}_{tot} \propto E_0$

$\hat{P}' \propto E_0^2$

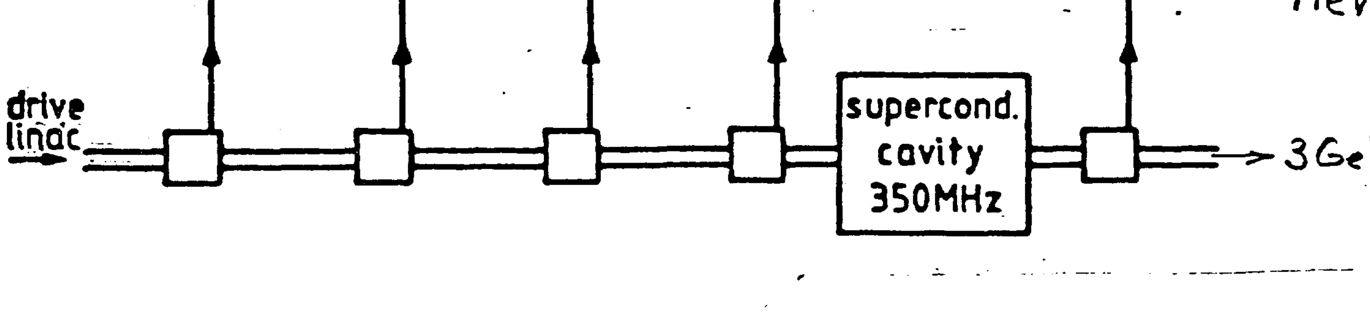
Two approaches followed:

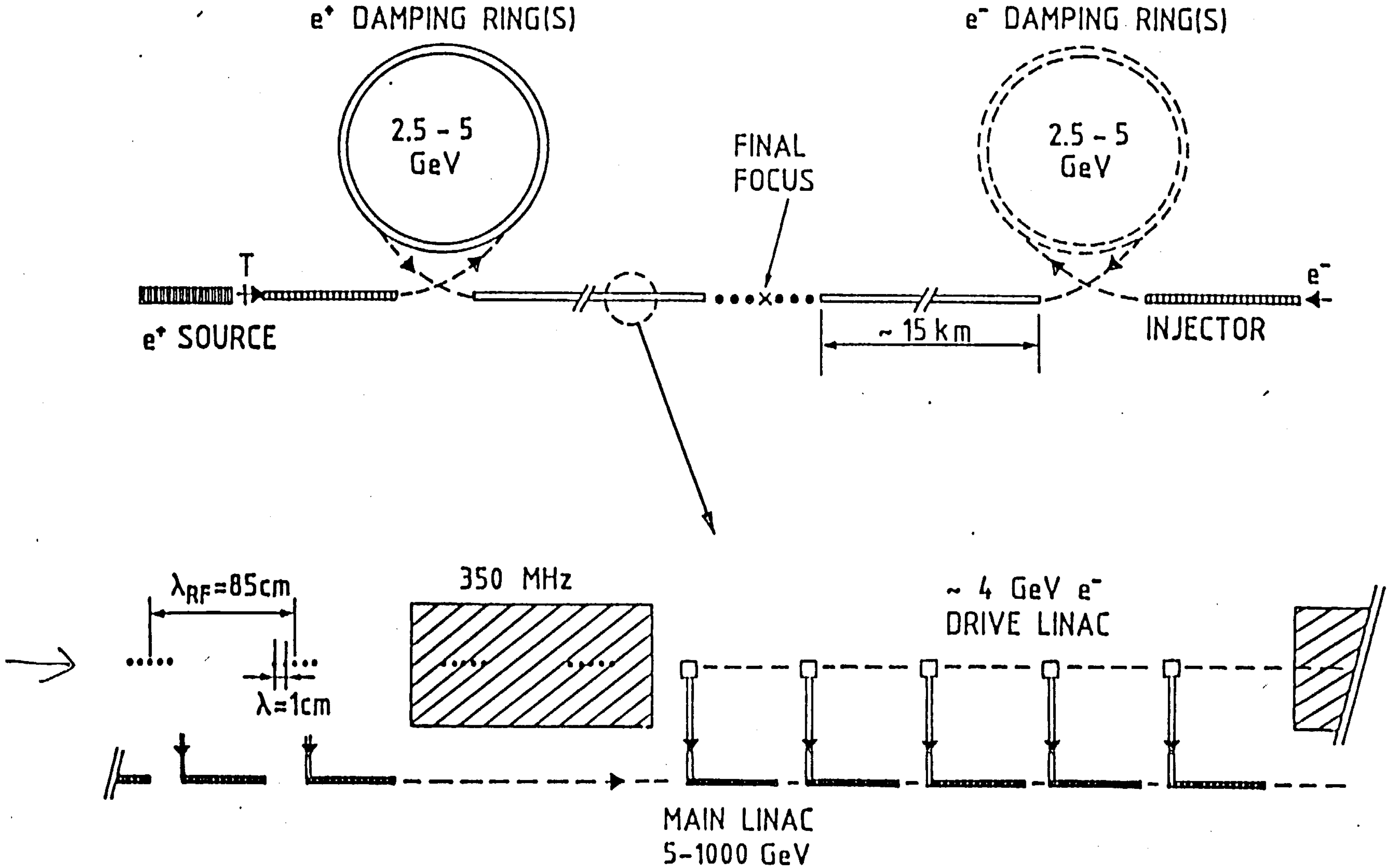
- Many dc to rf converters (thousands to tens of thousands)

- An auxiliary beam (MeV to GeV) parallel with the main linac; "Drive beam

TBA (Sessler) MeV drive beam
Induction units f. drive
FEL or "relativistic Klystr."
cavities for transfer

CERN Two-Stage – GeV drive beam
– Superconducting RF cavities for drive
– Travelling wave transfer structures





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3.2

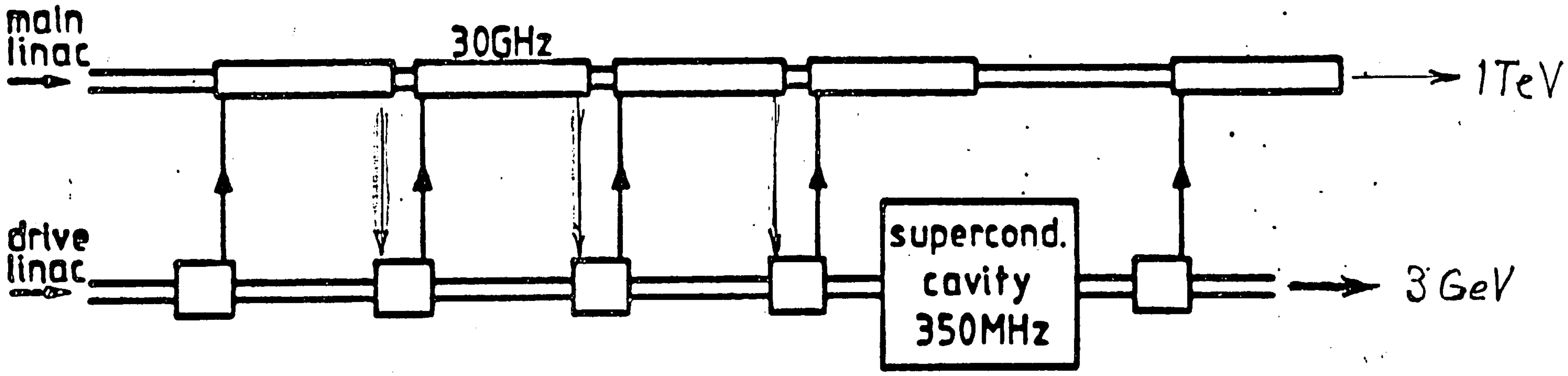
3 sets of parameters main linac and drive linac (per linac)

MAIN LINAC ENERGY	eU	1	1	1	TeV
MAIN LINAC FREQUENCY	f	29	29	29	MHz
MAIN LINAC ACCELERATING GRADIENT	E_o	80	160	445	MV/m
MAIN LINAC ACTIVE LENGTH	L_{tot}	12.5	6.25	2.24	km
DRIVE LINAC VOLTAGE GAIN	U_1	15	12	33.6	GV
DRIVE LINAC FREQUENCY	f_1	350	350	350	MHz
DRIVE LINAC R OVER Q PARAMETER	r_1'	270	270	270	Ω/m
DRIVE LINAC ACCELERATING GRADIENT	E_1	6	15	15	MV/m
DRIVE LINAC ACTIVE LENGTH	mL_{tot}	2.5	0.8	2.24	km
DRIVE LINAC QUALITY FACTOR	Q_1	5×10^9	5×10^9	5×10^9	
CRYOGENIC INPUT POWER ($\eta_{cr} = 0.2\%$)	$\langle P_1 \rangle / \eta_{cr}$	35	67	186	MW

- First column: present-day supercond. cavities = LEP-2 cavts!
- Second and third col.: Supercond. gradient improved 2.5 x
  (col. 3 does need multibunching)

N. Sch. 3.26

Energy recovery:



Energy recovery after main beam has passed.

Connect each main linac section to subsequent transfer structure.

Recovery beam pulse follows drive beam pulse, gets <u>acc</u>elerated in transfer str., <u>de</u>celerated in supecond. cavities

Gains factor 2 in av. power

May gain more in special standing-wave fast-fill structure (H. Henke '88)

Some major problems that need futher analysis:

- Emittance shaping (damping)
- Interaction region:
  - Final focus
    - Possible?
    - By which means?
    - Compatible w. detectors?
  - Disruption, positive and negative consequences
  - Beam radiation
  - Vacuum?
  - Polarisation?
- Tolerances
  - for accelerator components
  - final focus

etc. etc.

Final paragraph of Report from the CLIC Advisory Panel (CLIC Note 38)

Despite the substantial technical challenges to be faced, we have strong confidence that effective practical solutions will be found and that therefore linear e^+e^- colliders may provide one of the ways for Europe to maintain its leading position in elementary particle physics.

From Concluding chapter of the final report from the LRPC (Rubbia)

6)—It is believed that the exploration of the next energy domain — broadly defined as ≈ 1 TeV— requires both a hadron collider and an e^+e^- collider with about 2 TeV in the centre of mass. The latter requires the development of an entirely new accelerator technology to which Europe, and CERN in particular, should contribute significantly. It is believed that these studies have a high probability to result in a realistic project which is both technically and financially sound and that it should become a part of the over all world strategy in High Energy Physics. To this effect, a full time team and an appropiate financial support are needed at once, in order to match the efforts in this field which are carried out elsewhere in the world.

My remarks: Balanced programme with highest priority on the normal conducting linear approach, but with a fair fraction of effort also on "exotic" ideas.