TESLA Project Overview

Advantages of superconducting cavities

for a linear collider

Due to low RF losses in the walls of
s.c. cavities

- High conversion efficiency from

  mains to beam power

- Long RF pulse possible

  Many bunches spaced far apart
  allowing

    head on collission

    fast bunch to bunch orbit feedback

Luminosity of e+/e- collider is given by:

$$L \approx \text{const} \cdot H \cdot P \, \frac{\sqrt{\delta}}{E} \, \frac{\eta}{\sqrt{\varepsilon}}$$

- H Luminosity enhancement factor caused by selffocussing
- E cm energy of collider
- δ average beamstrahlungs loss
- P mains power
- η conversion efficiency mains to beam power
- ε normalised vertical emittance at IP

→

To achieve high luminosity

high conversion efficiency

and

small vertical emittance at I.P.

are needed

A very relevant quantity in optimizing the performance of a Linac is the shuntimpedance per unit length

$$\frac{(\text{Accelerating Gradient})^2}{\text{RF loss per unit length}}$$

This quantity depends on RF frequency ω

for normalconducting acc. structures

$$\sim \sqrt{\omega}$$

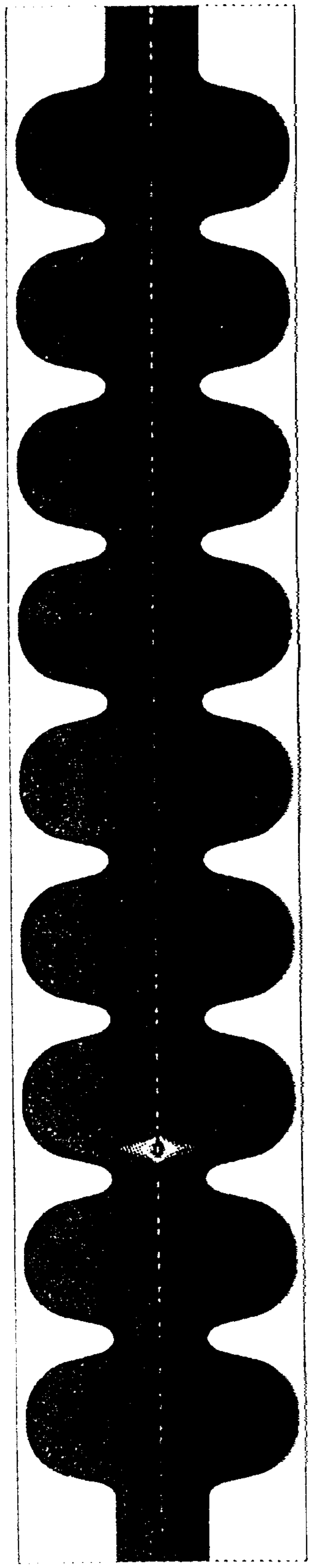
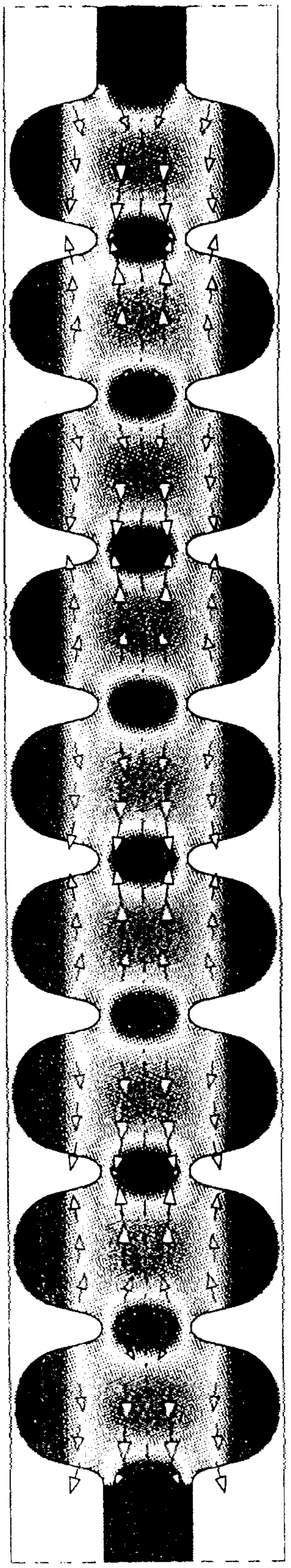
Thus favouring high RF frequencies

For superconducting acc. structures it scales approximately like

$$\frac{\omega}{A\omega^2 + B}$$

Favouring RF frequencies around

~ 1 GHz

TRANSVERSE WAKEFIELDS

$W_\perp \sim \omega^3$

At high beam intensities more severe limits on trajectory correction are required due to transverse wakefield-induced emittance enlargement. Effects of wakefields are clearly seen, as indicated in Fig. 6 where oscillations of 1 mm cause severe beam blowup at 2×10^{10} electrons per bunch.

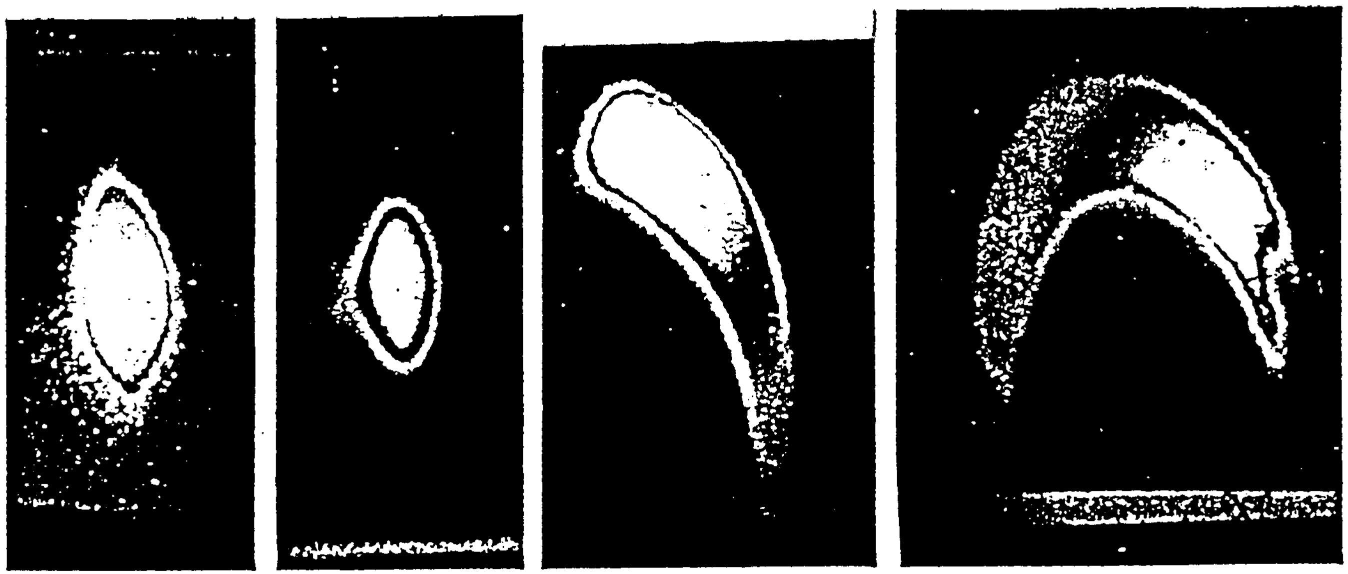


FIGURE 6 Images of an e^- beam on a profile monitor showing wakefield growth with increasing oscillation amplitude. The left image is for a well-steered beam and the right one for an oscillation amplitude of 1 mm. The beam intensity is 2×10^{10} electrons. The core sizes σ_x and σ_y are about 120 μm.

As low RF frequencies are preferred

for s.c. cavities

→ Ideally suited to accelerate

low emittance beam

as emittance dilution by wakefields

is small $W_\perp \sim \omega^3$

$$L \sim \frac{\eta}{\sqrt{\varepsilon}}$$

The combination of high conversion efficiency from mains to beam power and small emittance dilution make superconducting linear collider the ideal choice with respect to achievable luminosity

Major challenges to be mastered

so that superconducting linear collider becomes feasible:

- Increase of gradient from ~5 MV/m to 25MV/m
- Cost reduction of structure per meter by ~4 to achieve 2000$/MV

Encouraged by R&D results from

CEBAF,CERN,Cornell,DESY,KEK,Saclay and Wuppertal

nucleus of TESLA collaboration decided in 1991 to set up infra structure at DESY

necessary to process and test 1.3Ghz sc Niobium cavities produced by industry

Members of the TESLA-Collaboration

Yerevan Physics Institute

IHEP
Academia Sinica, Beijing

Tsinghua-University, Beijing

Institute of Physics,
Helsinki

CEA/DSM
(DAPNIA, CE-Saclay)

IN2P3
(IPN Orsay + LAL Orsay)

RWTH Aachen

Max-Born-Institut,
Berlin-Adlershof

TU Berlin

TU Darmstadt

TU Dresden

Universität Frankfurt

GKSS, Geesthacht

DESY, Hamburg und Zeuthen

Universität Hamburg

FZ Karlsruhe

Universität Rostock

Universität Wuppertal

INFN Frascati

INFN Legnaro

INFN Milano

INFN and Univ. Roma II

Polish Academy of Science

University of Warsaw

Institute of Nuclear Physics,
Cracow

Univ. of Mining & Metallurgy

Polish Atomic Energy
Agency

Soltan Inst. for Nuclear
Studies, Otwock-Swierk

JINR Dubna

IHEP Protvino

INP Novosibirsk

INR Troitsk

ANL
Argonne IL

Cornell University,
Ithaca NY

FNAL,
Batavia IL

UCLA
Los Angeles CA

Januar '99

Work on concept of superconducting linear collider was pursued

Energy 500 GeV

RF frequency 1.3 GHz

Gradient 25 MV/m

Q-value $5\ 10^9$ $L \sim 5\ 10^{33} cm^{-2} sec^{-1}$

Conceptual design report (CDR) was published in 1997

Two sites: DESY and FERMILAB

complete description of collider including all subsystems

includes joint study with ECFA on particle physics and detector

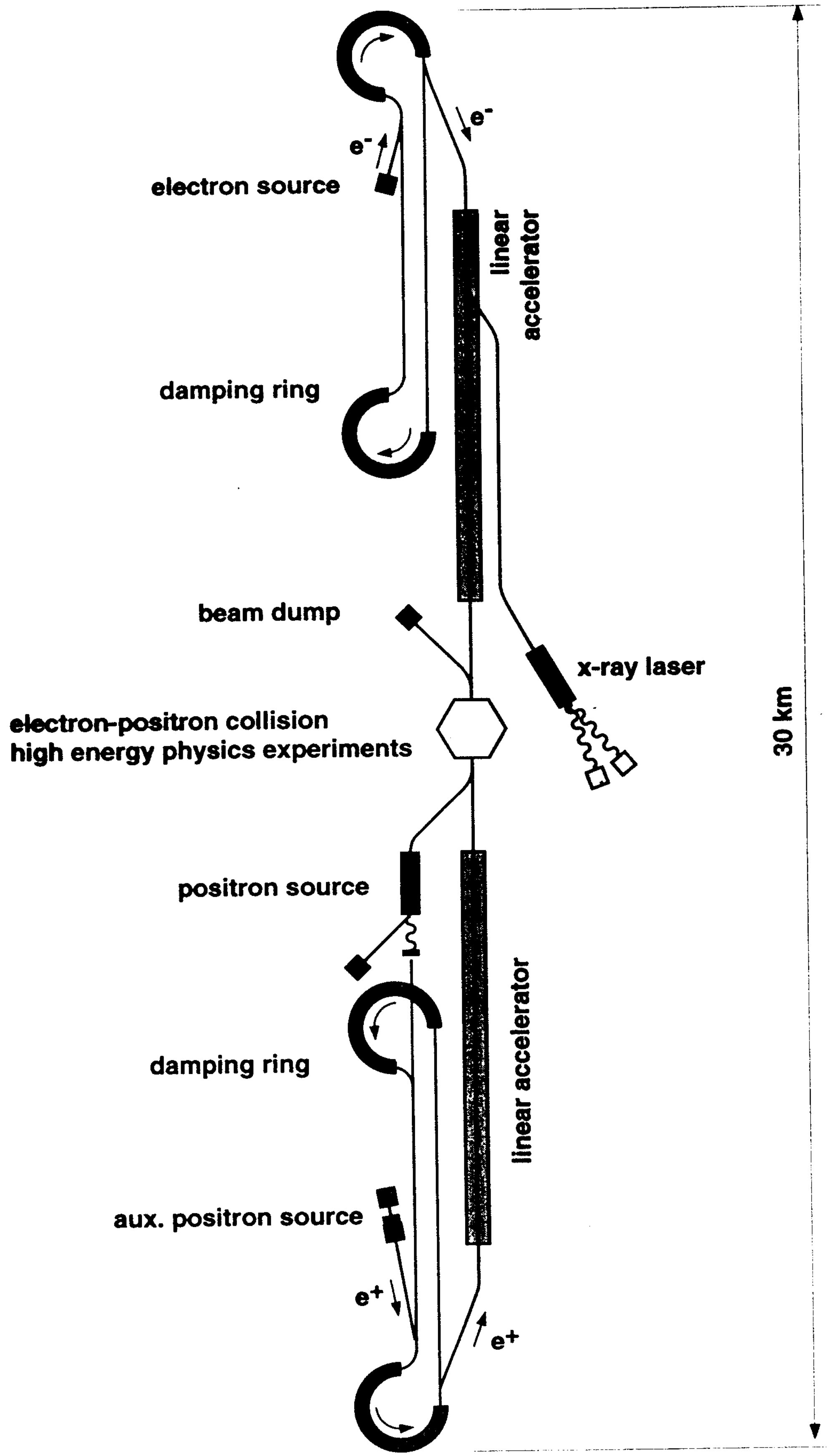
Since 1990 growing interest in X-ray FEL based on SASE principle

Requirements on emittance very demanding

→ s.c. structures ideal for acceleration

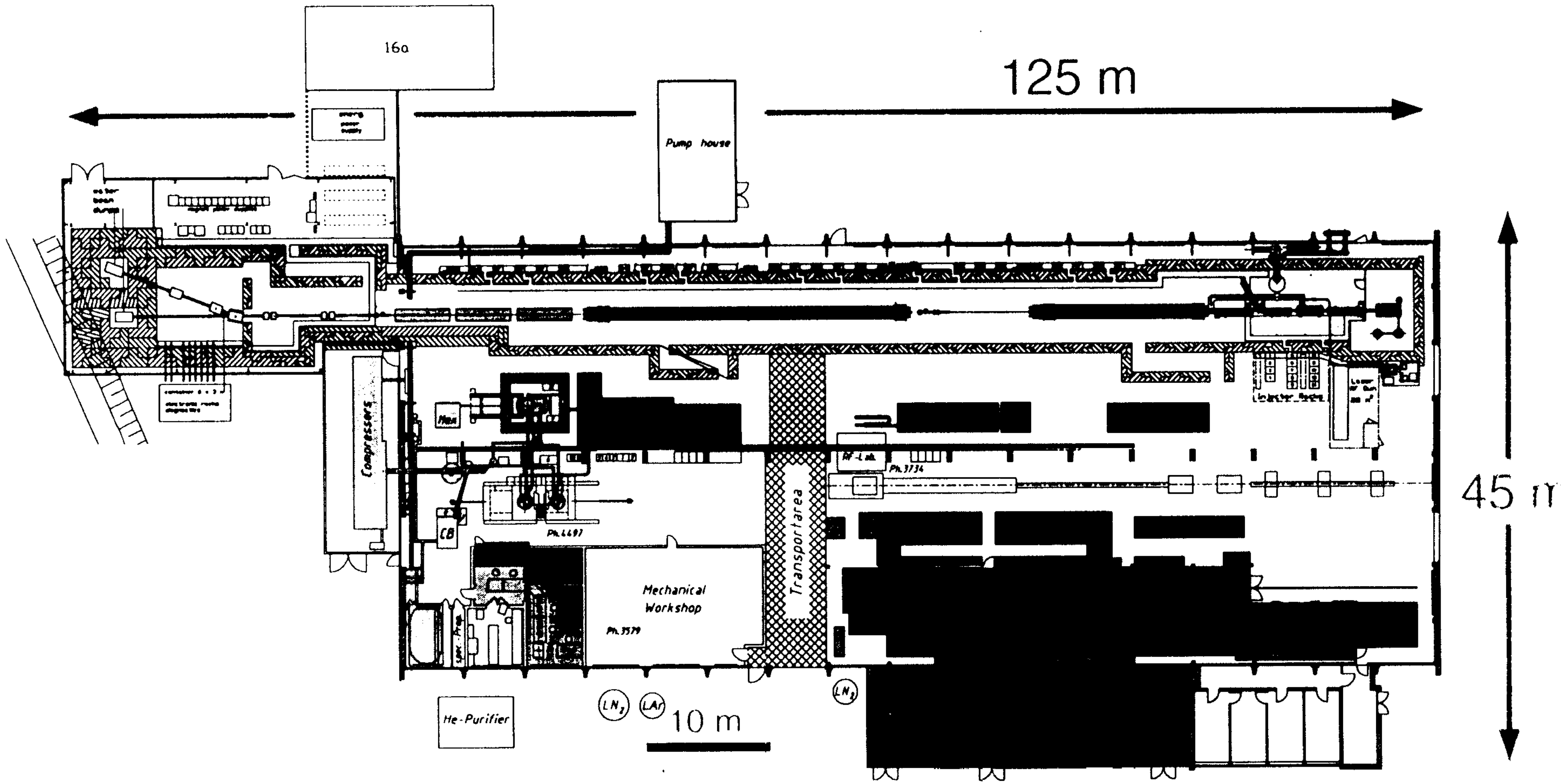
CDR includes layout of X-ray FEL facility

integrated into the linear collider facility



electron source
e-
e-
linear accelerator
damping ring
beam dump
x-ray laser
electron-positron collision
high energy physics experiments
30 km
positron source
damping ring
linear accelerator
aux. positron source
e+
e+

TESLA TEST FACILITY (HALL 3)



Cavity Treatment and Assembly

Cavity Testing (RF System / He Plant)

TTF Linac

H.Weise / June 24th, 1996

Initial goal for the TESLA Test Facility TTF

gradient 15 MV/m

Q-value $3\ 10^9$

Infrastructure

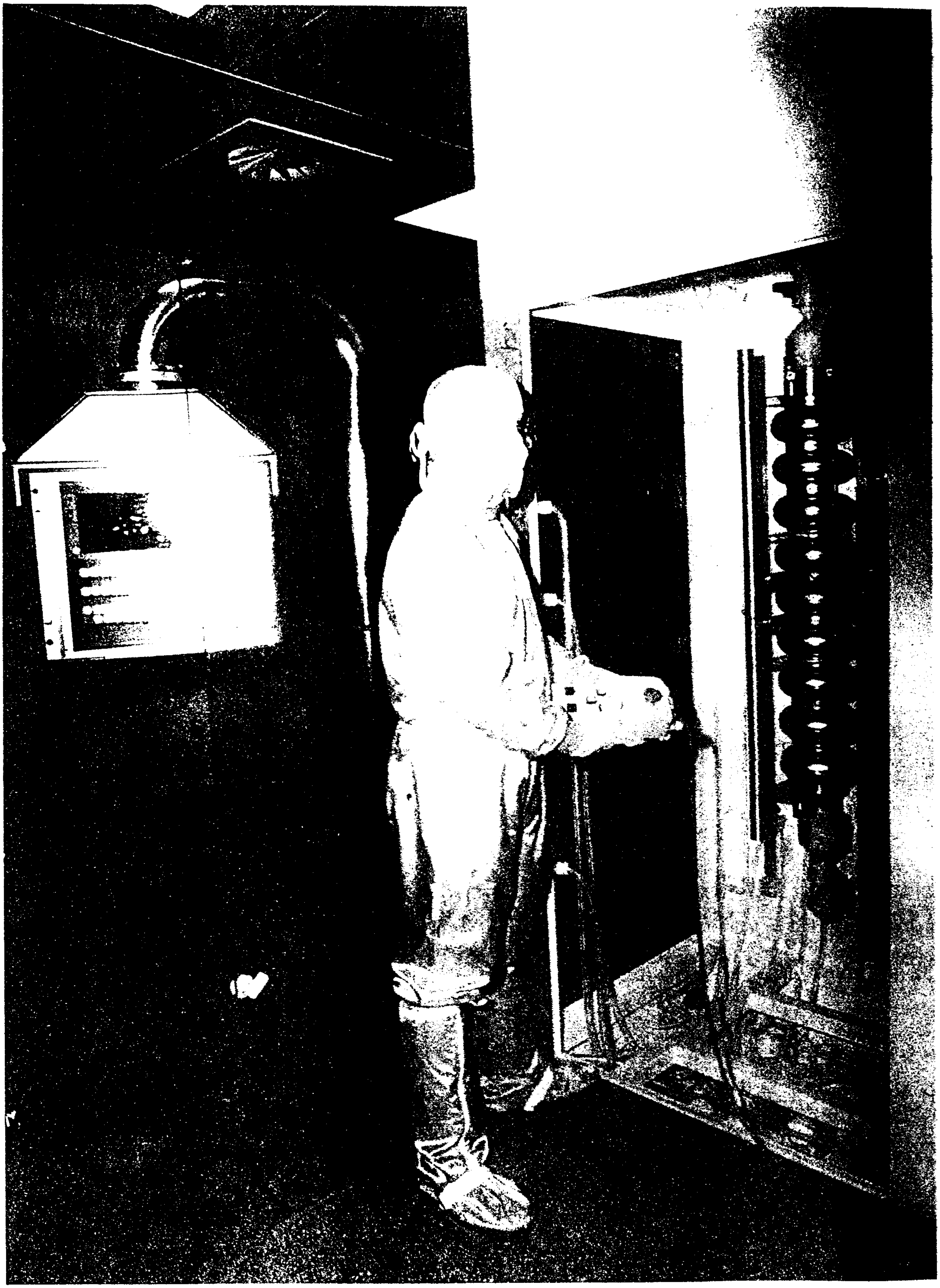
cleanrooms automatic chemistry high pressure rinsing	with substantial help of CERN
furnace 1500 C	Cracow
cryogenics for 1.8 K	substantial contributions by Fermilab
2 vertical Test kryostats	Fermilab
horizontal Test kryostat	Saclay
1.3 GHz RF system	Fermilab

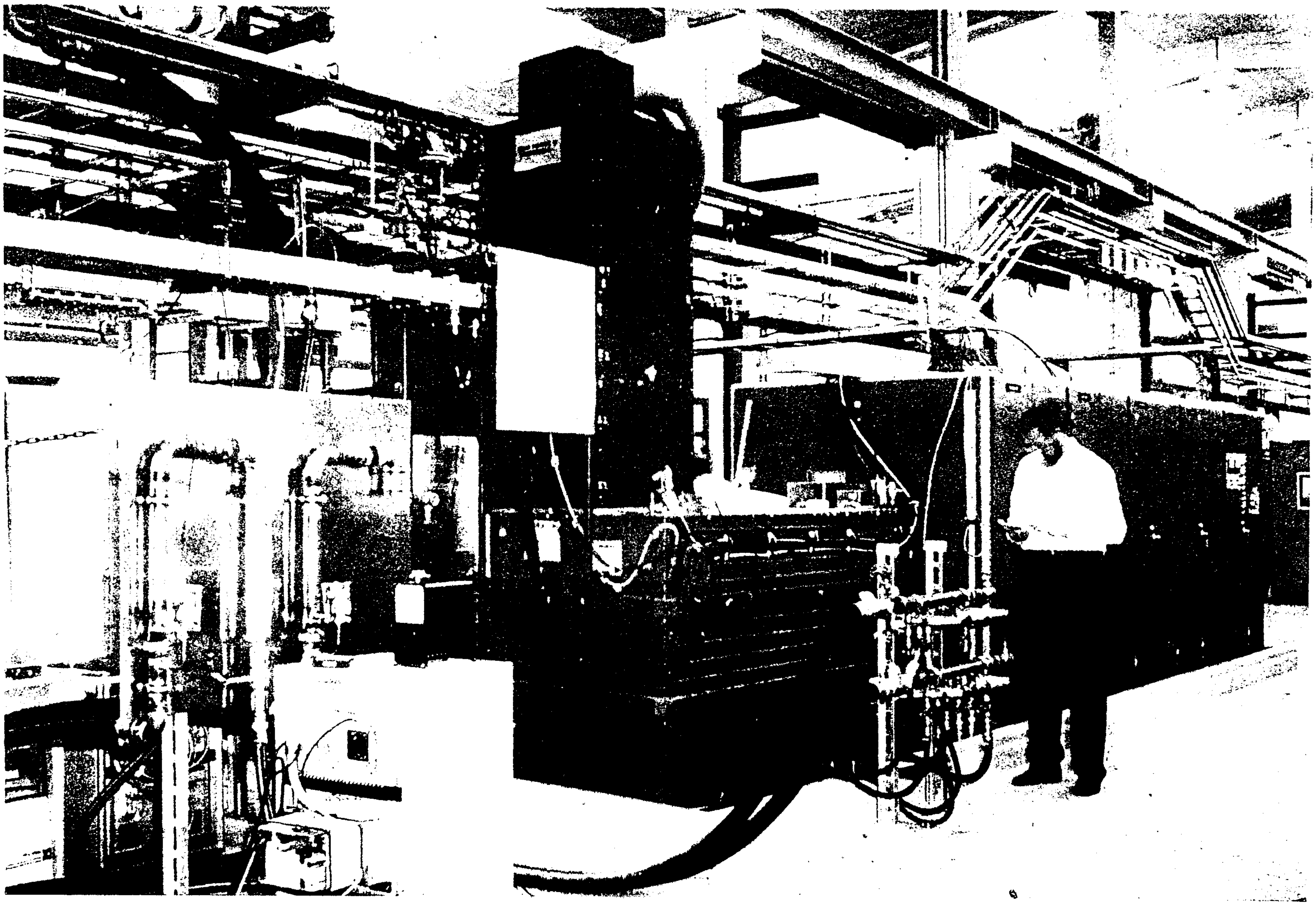
FIRST SERIES OF CAVITIES DESY/INFN/SACLA

COUPLERS FERMILAB

HOM COUPLERS SACLAY / DESY

TUNERS SACLAY

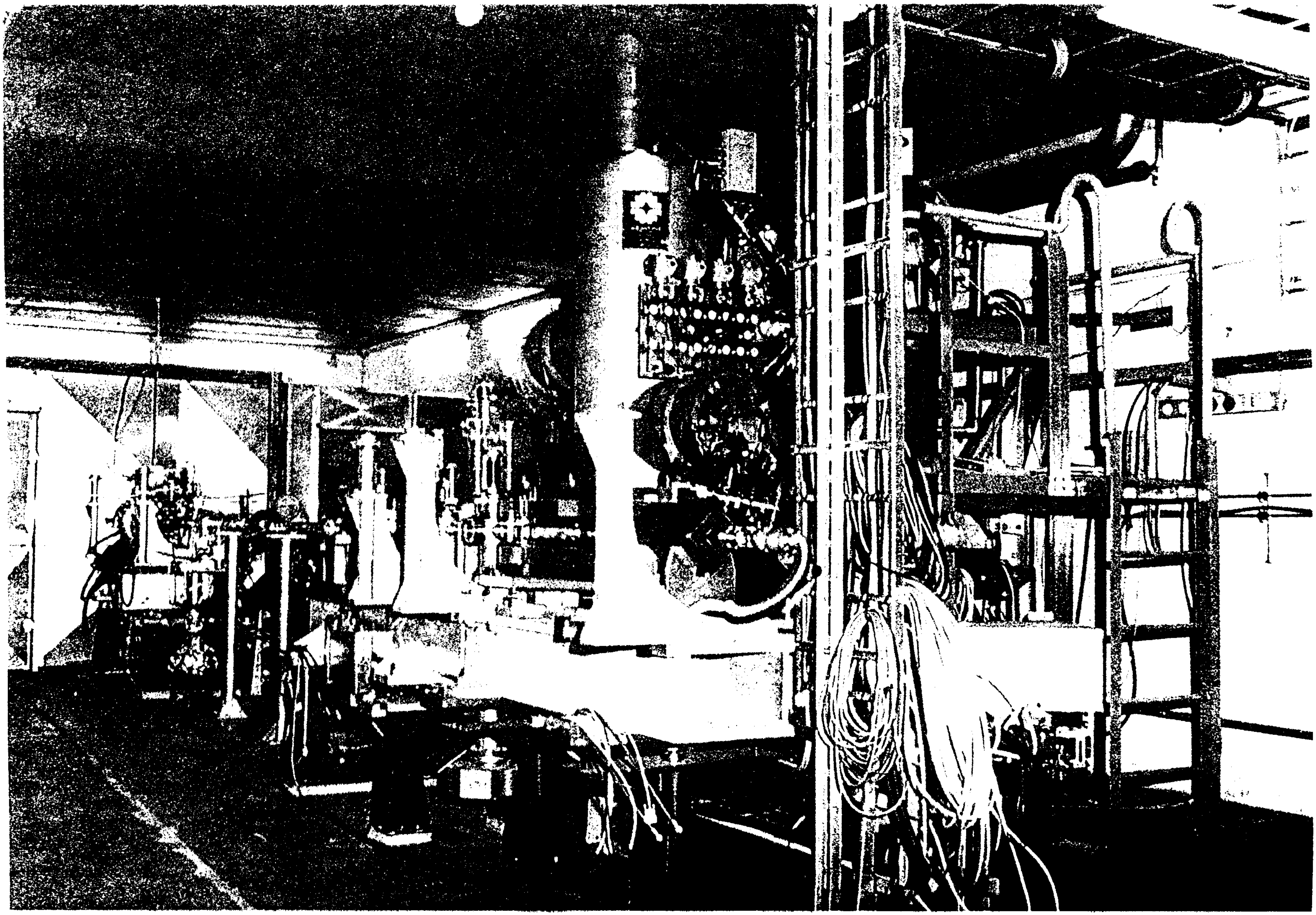


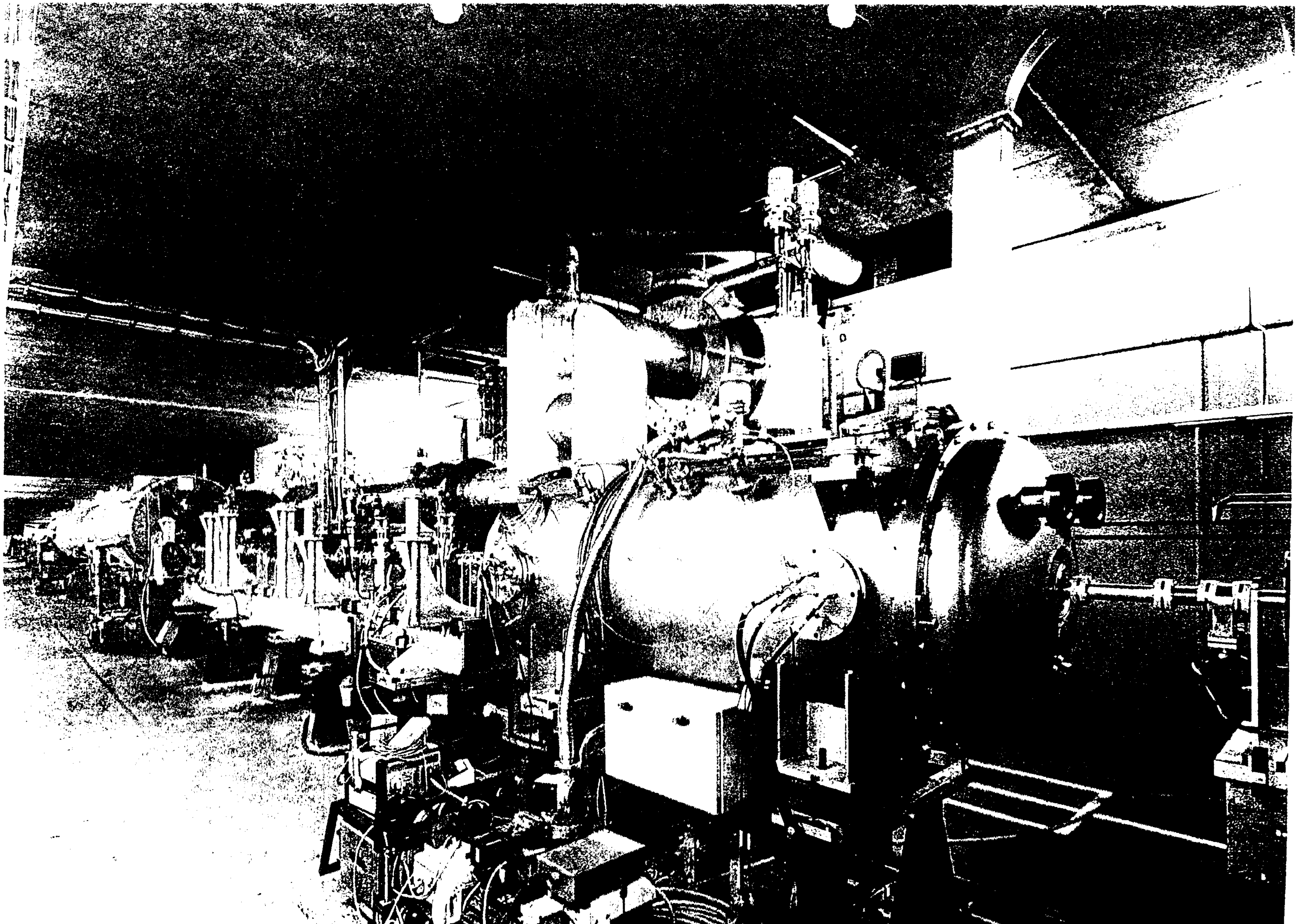


Test Linac

as an integrated systems test to demonstrate that a linear collider based on s.c. cavities can be constructed and operated with confidence

Max Born Inst. UCLA Fermilab INFN	RF-Gun
Orsay Saclay	Injector
INFN Fermilab	4 Cryostat Modules
TU Berlin Cracow INFN Orsay Protvino Yerevan	Instrumentation Controls
Protvino	Beam Dumps
Dubna Fermilab INFN Protvino Yerevan	Magnets
Fermilab Protvino Orsay	Cryogenics





Ingredients for cost reduction:

- **Long cavities 9 cells**

  → Fewer input couplers
  HOM couplers
  Tuners
  Vacuum vessel penetrations
  Waveguides
  .
  .

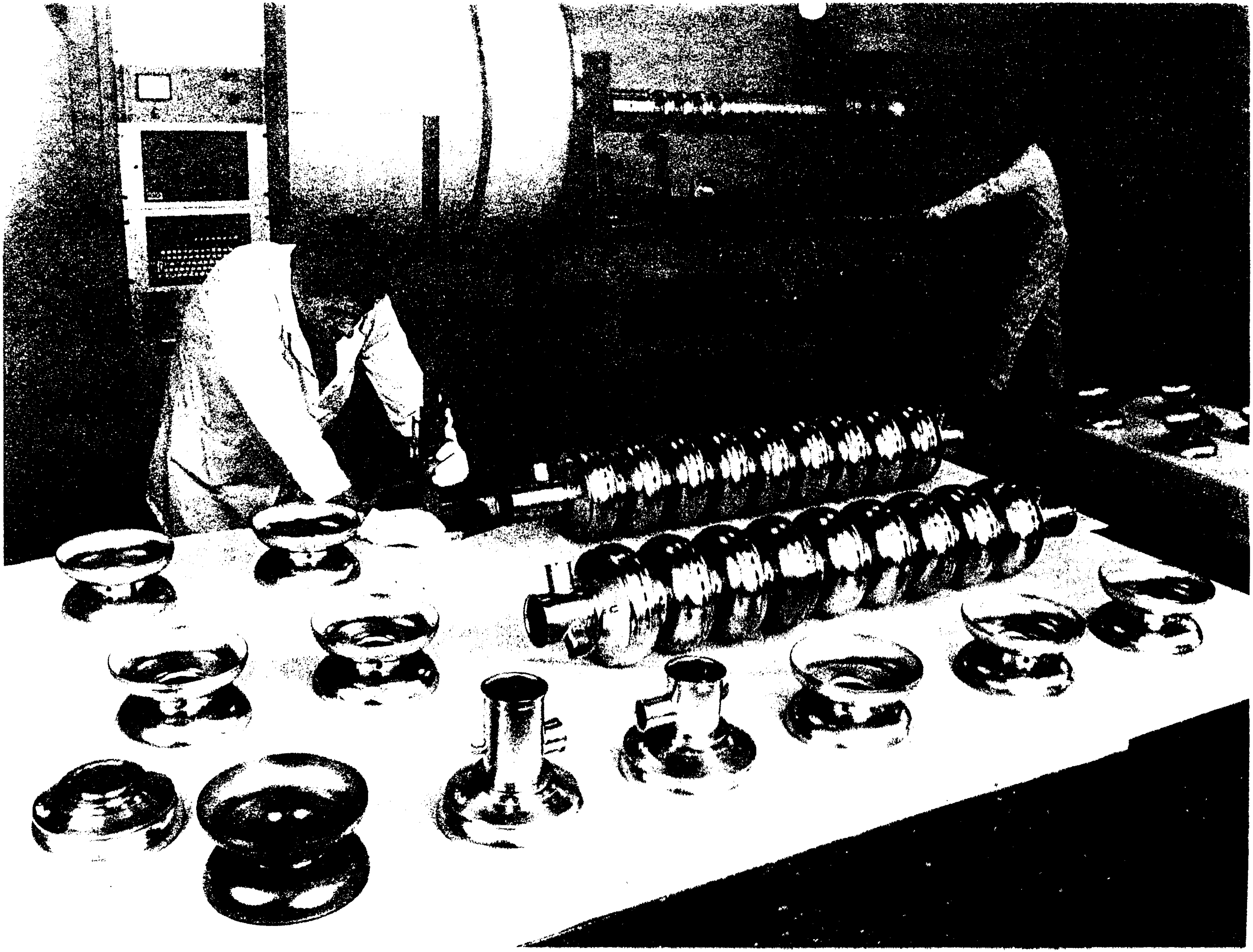
- **Long modules containing 8 cavities plus sc magnets**

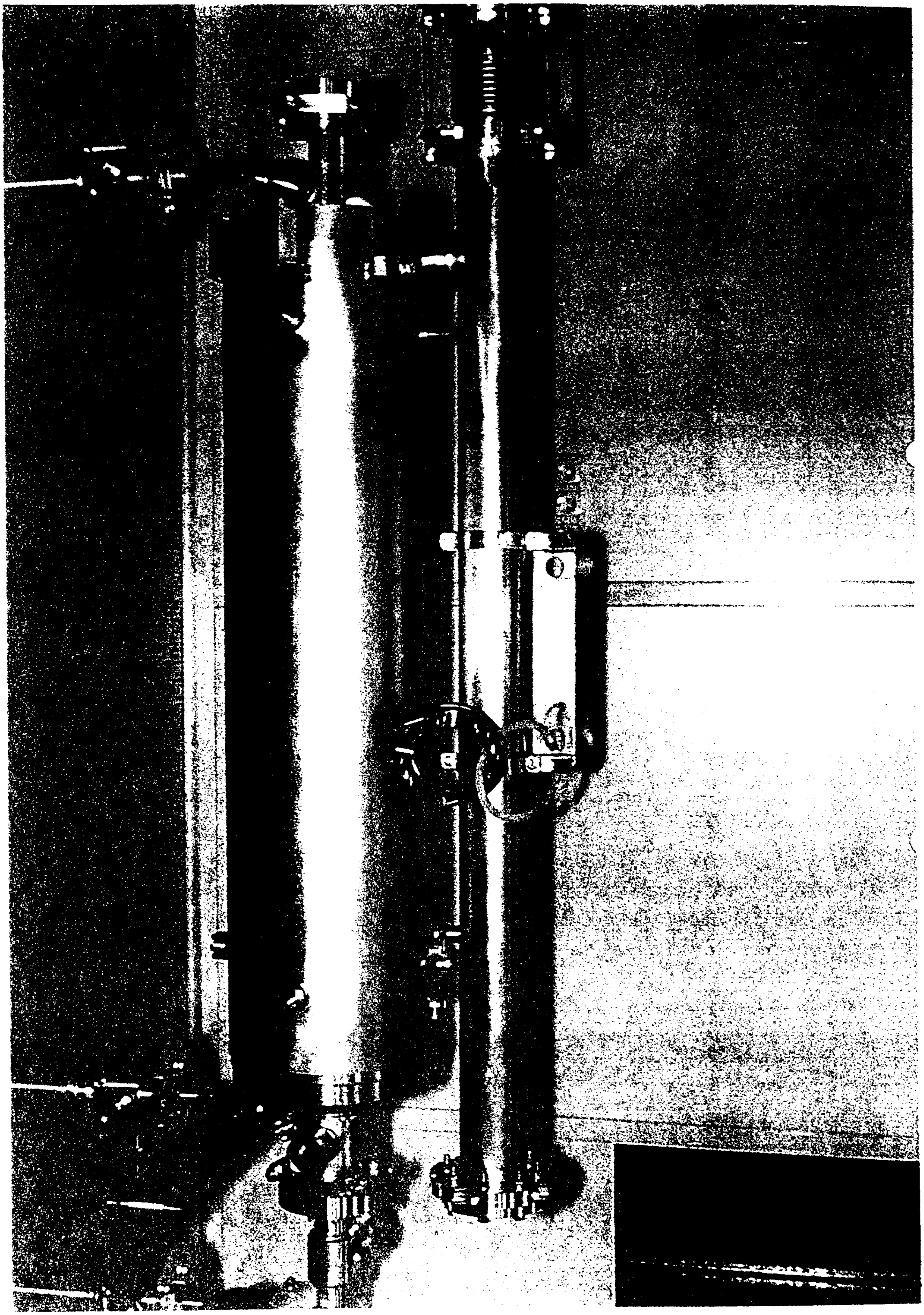
Connection of many modules to long cryogenic string (~2.5km)

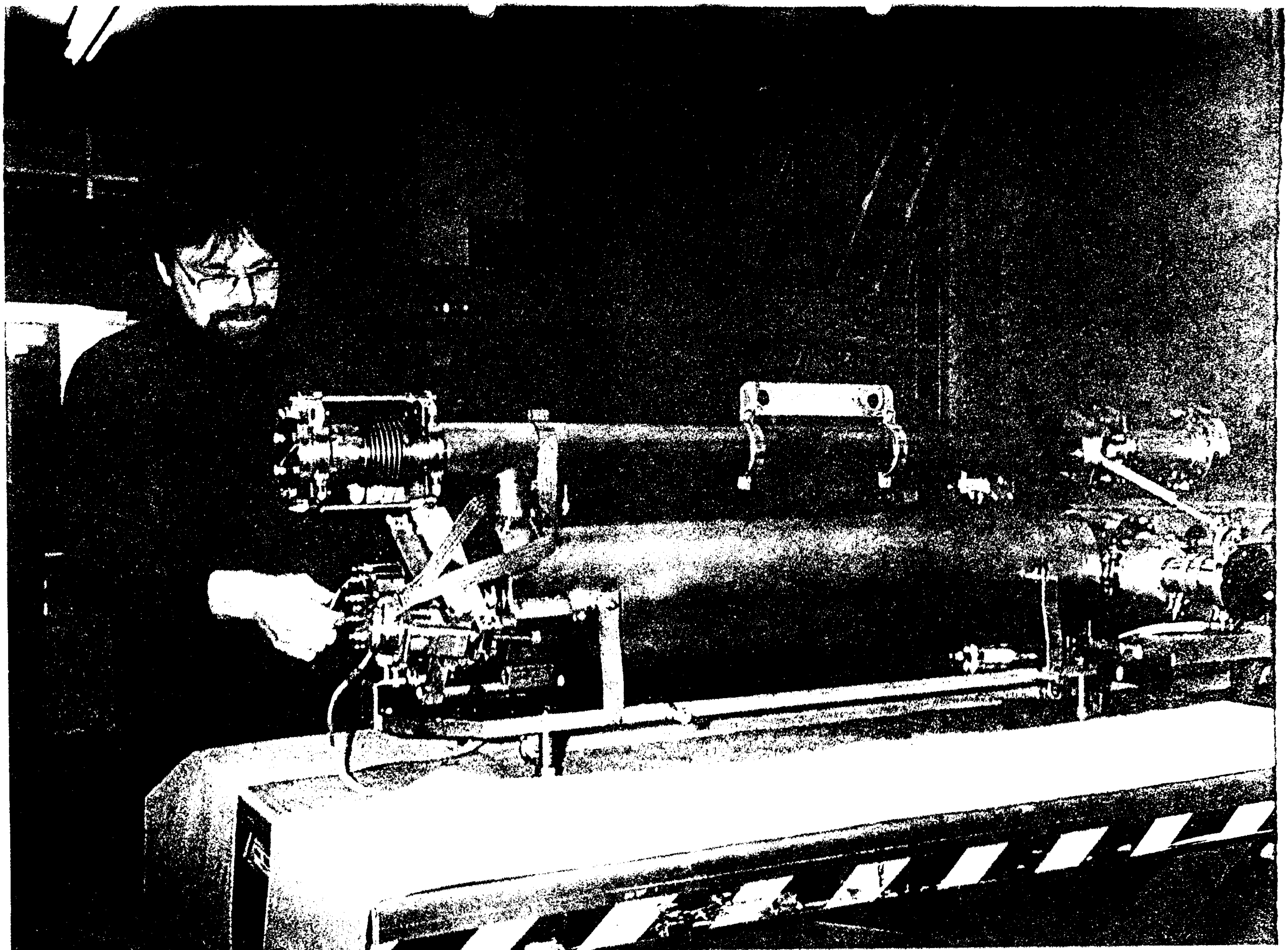
Incorporation of Helium distribution into cryostat

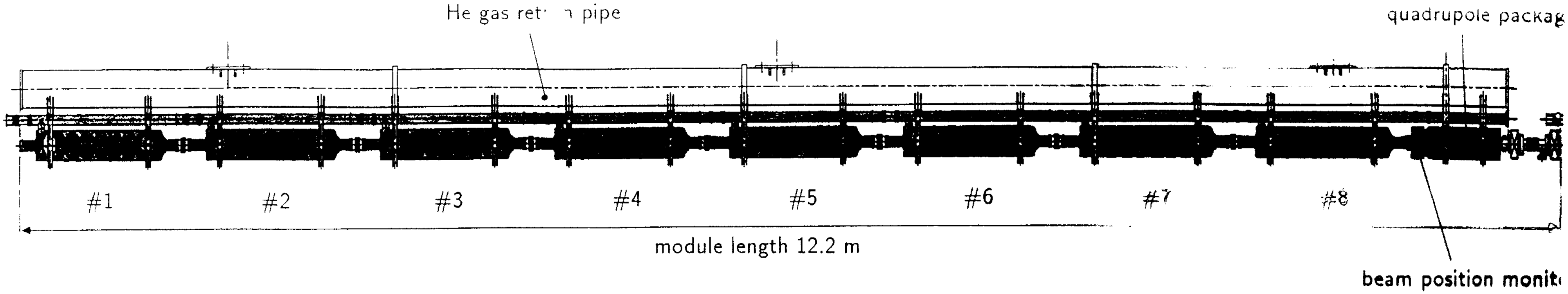
→ **Much cheaper and simpler Helium distribution system**

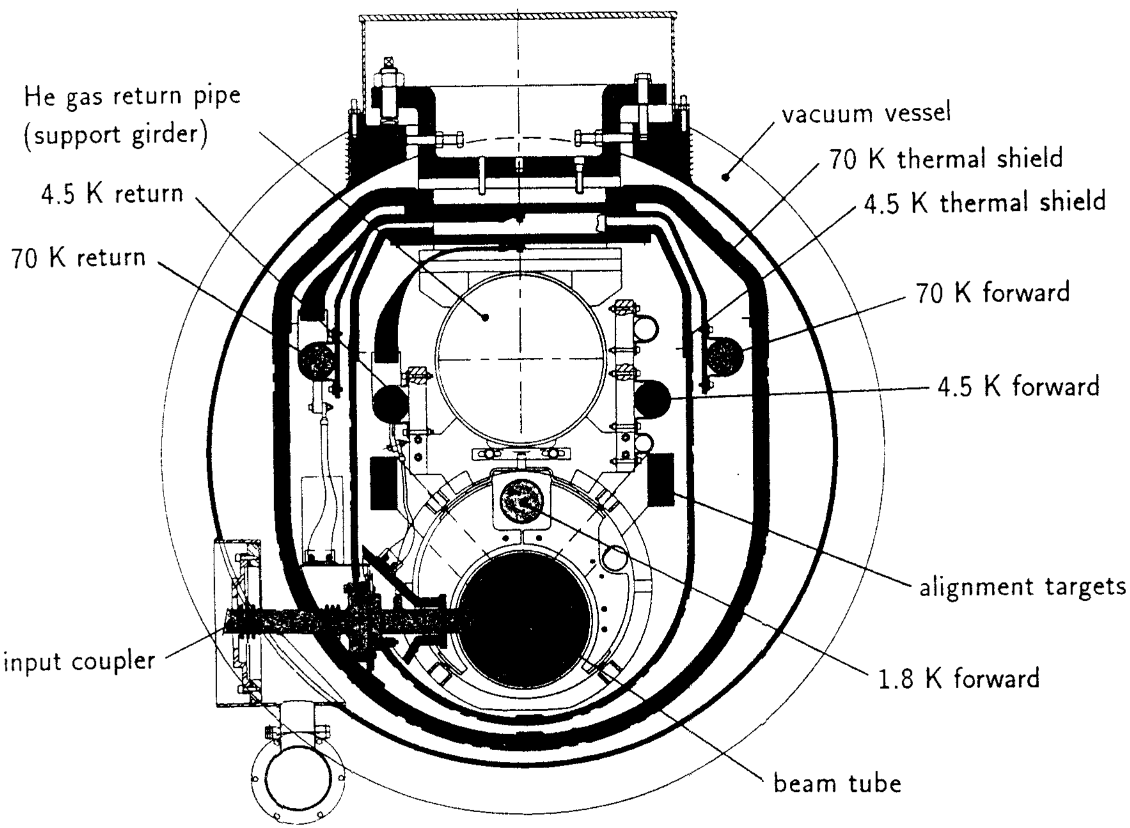
No costly warm to cold transitions





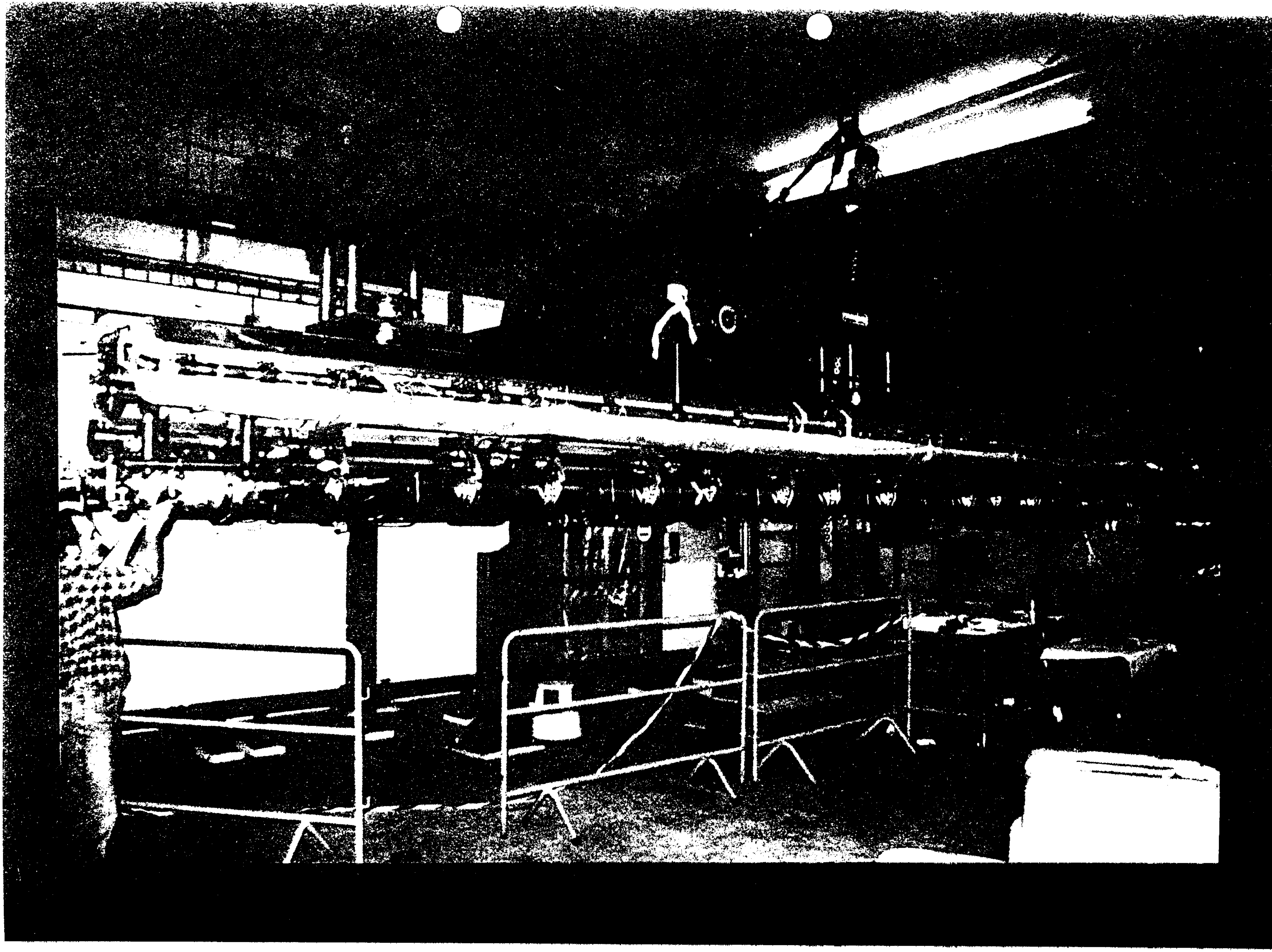


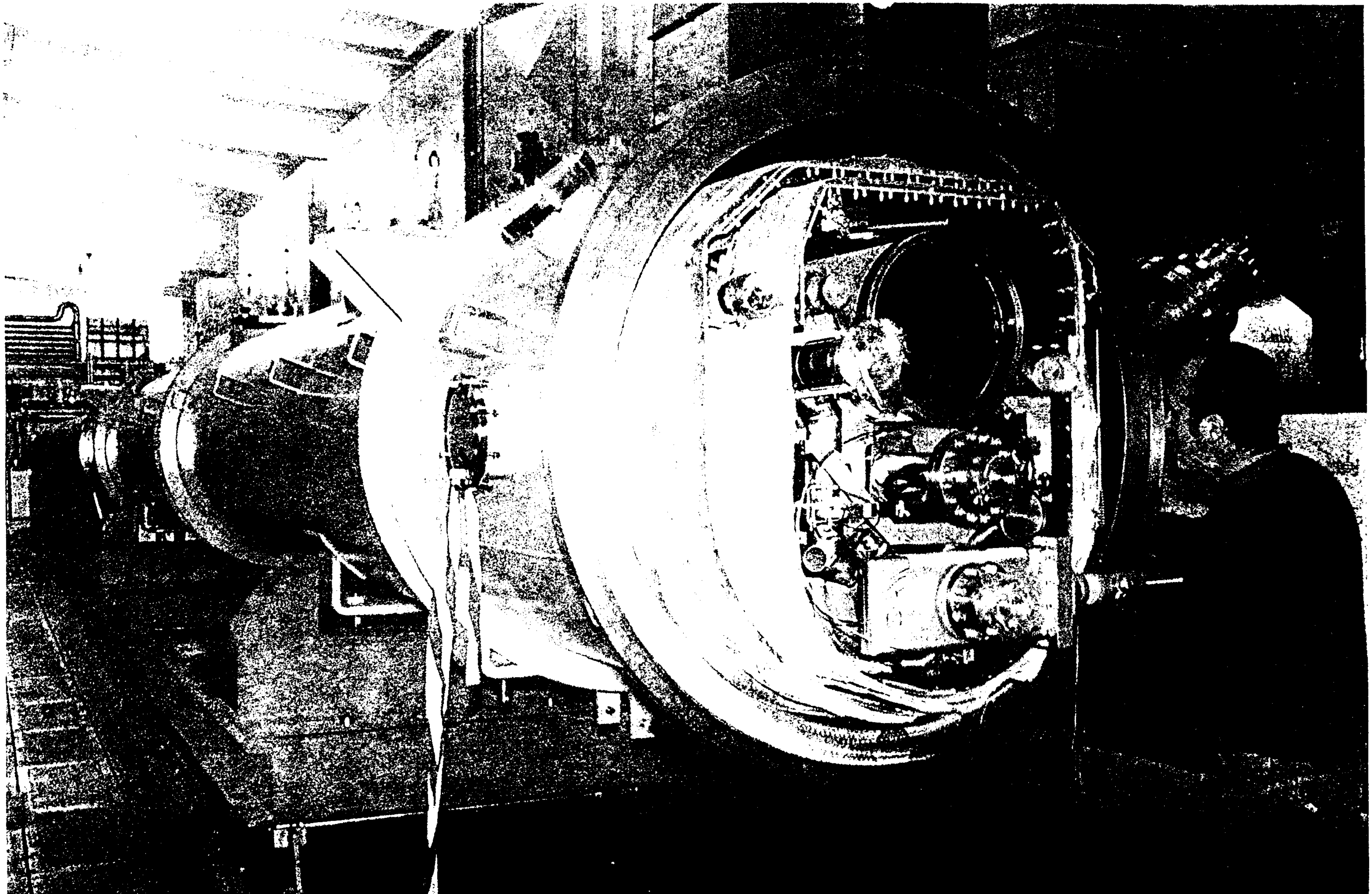


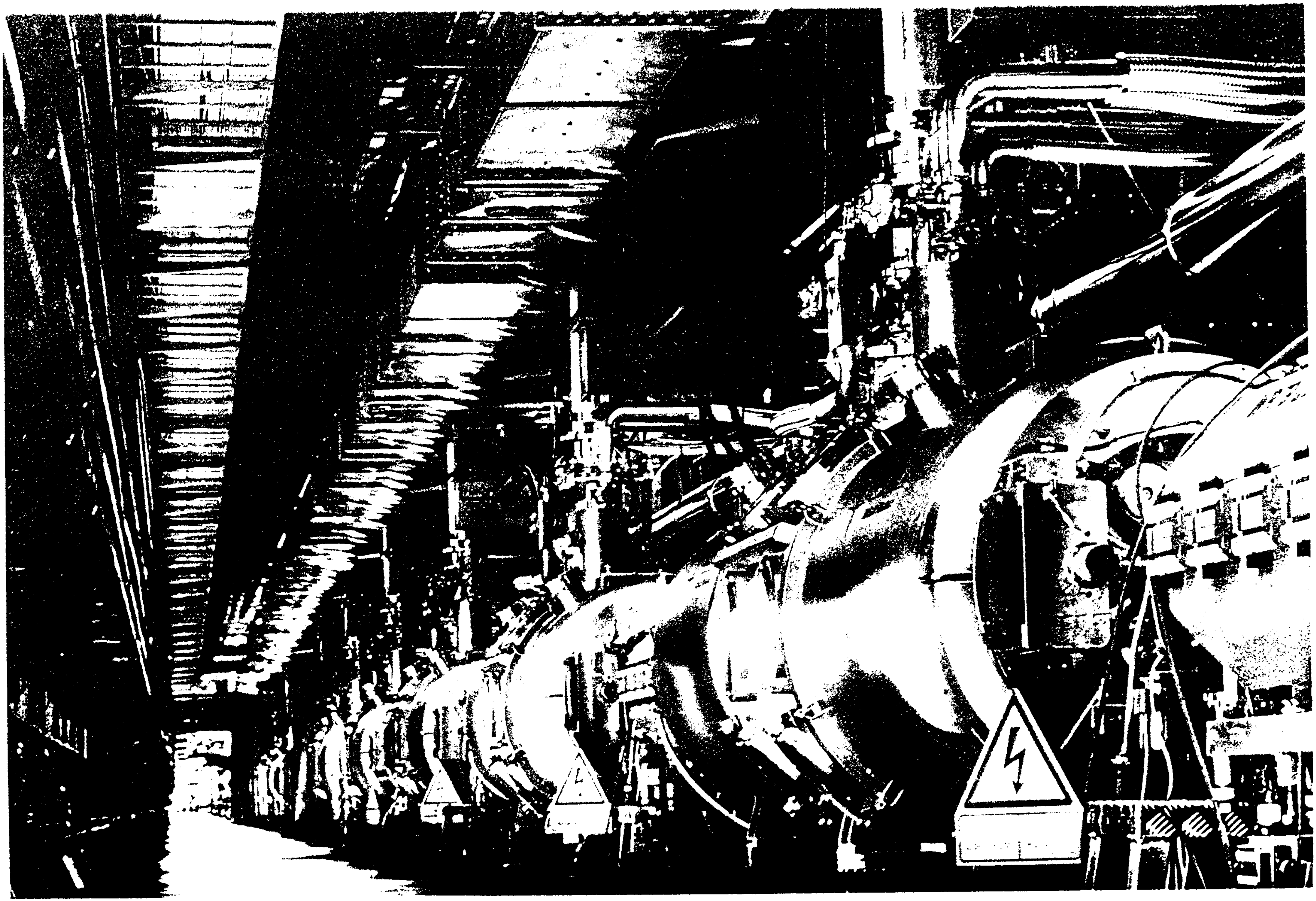


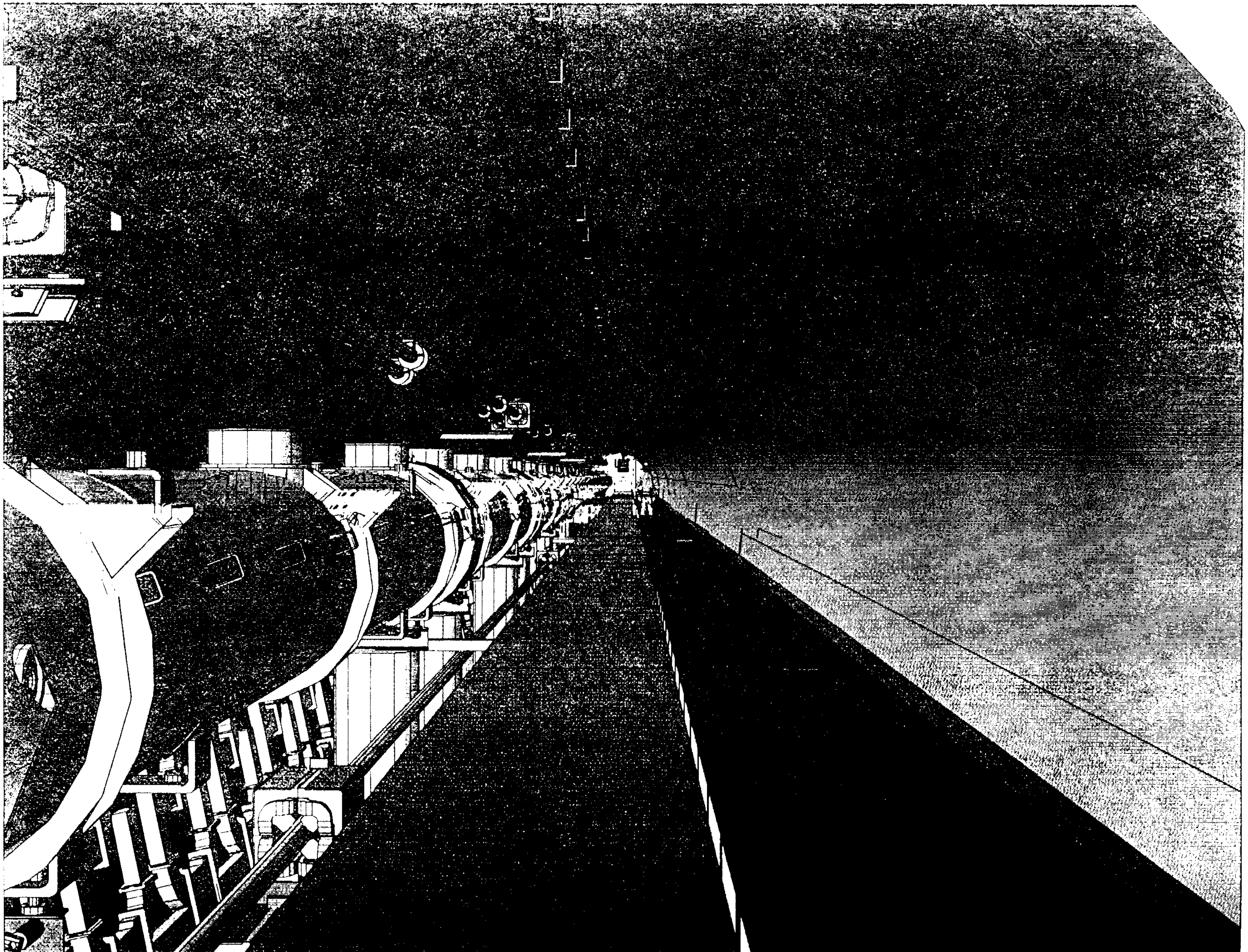
- He gas return pipe (HeGRP) is supported from above by three support posts (fiberglas pipe): it acts as a girder and is used for alignment
- the 8 cavities, the quadrupole package and aux.equipment are attached to the HeGRP by means of stainless steel collars
- two aluminium radiation shields are at intermediate nominal temperatures of 4.5 K and 70 K: they are cooled by means of flexible cooper braids connected to the centerline of the shield upper section
- the input coupler penetrate both shields and have special radiation shield 'cones'
- approx. 128 temperature sensors and 2 accelerometers are foreseen on the prototype cryomodule
- the anticipated static heat load budget for one cryomodule is

  $\lesssim$ 4 W @ 1.8 K
  $\approx$ 14 W @ 4.5 K
  $\approx$ 120 W @ 70 K









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A very important new development

" superstructure " concept

Spacing of adjacent cavities reduced from 1.5 to 0.5 RF wavelength

Filling factor of linacs increases from

66 → 76 %

For fixed linac length required gradient for 500 GeV

25 → 21.7 MV/m

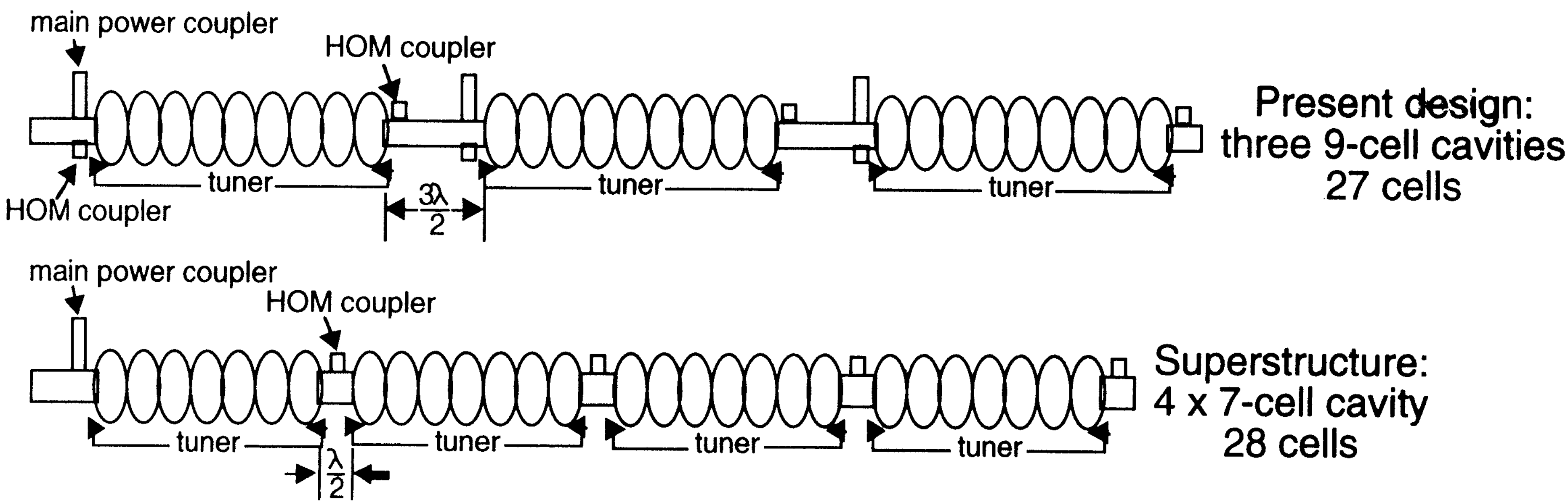
4 or more cavities are fed by ONE input coupler

Obvious cost reduction by

smaller number of Input couplers
Cryostat penetrations

simplification of RF distribution

TTF design <-> Superstructure design



	TTF	Superstr.
cells per cavity	9	7
radius mid/end iris [mm]	35/39	35/57
fill factor cavity	0.75	0.875
E_{peak}/E_{acc}	2.0	2.0
B_{peak}/E_{acc} [mT/(MV/m)]	4.2	4.2
coupling cell to cell k_{cc}	0.02	0.02
field instability factor N^2/k_{cc}	4.3	2.6
coupling cavity to cavity	-	0.0004

	TTF	Superstr.
# FM couplers	19230	6181
# HOM couplers	38460	24724
# tuners & vessels	19230	24724
FM coupler power [kW]	208	640
fill factor linac	0.66	0.76

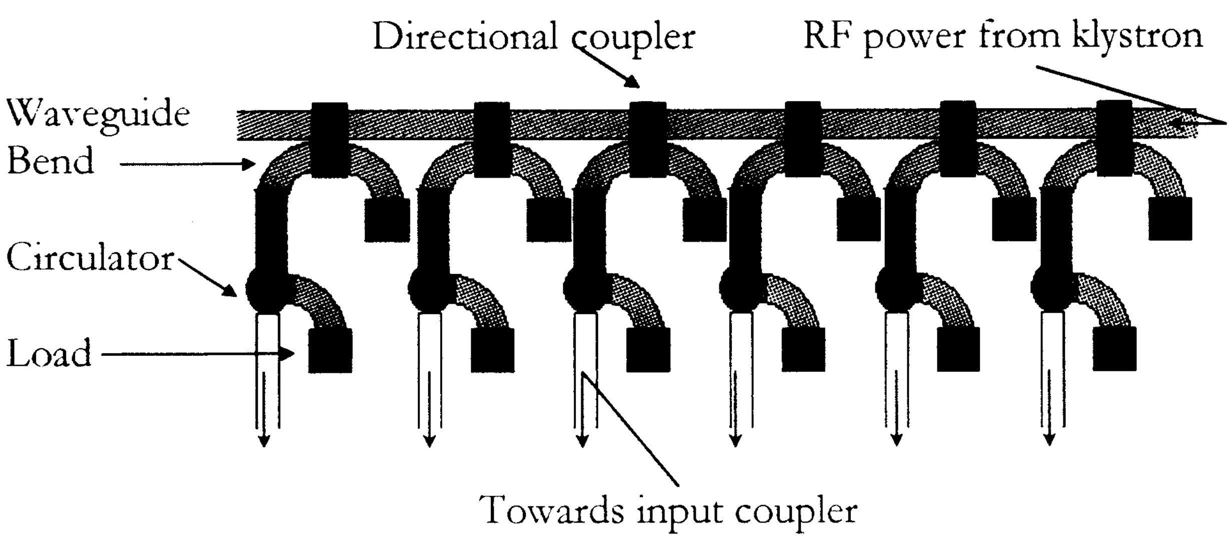
3. Final remarks

- Changes in the RF system

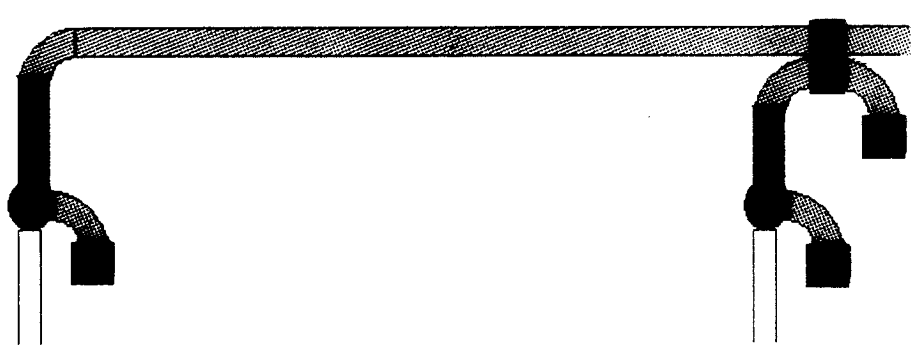
Table 4. Number of input couplers and HOM couplers.

	present design	superstructure
number of input couplers	19230	6181
number of HOM couplers	38460	24724

RF power distribution system for 54 cells (6 structures) in the present layout of both linacs.



RF power distribution system for 56 cells (2 superstructures).



Many of expensive RF components like circulators, loads, waveguide bends and directional couplers can be spared.

Updated parameters at E_{cm}=500GeV in comparison with the original reference parameters

	TESLA (ref.)	TESLA (new)
site length [km]	32.6	32.6
active length [km]	20	23
acc. Gradient [MV/m]	25	21.7
quality factor Q_0 [10^{10}]	0.5	1
t_{pulse} [μs]	800	950
# bunches n_b/pulse	1130	2820
bunch spacing Δt_b [ns]	708	337
rep. rate f_{rep} [Hz]	5	5
N_e/bunch [10^{10}]	3.6	2
ε_x / ε_y (@ IP) [10^{-6}m]	14 / 0.25	10 / 0.03
beta at IP $\beta_{x/y}^*$ [mm]	25 / 0.7	15 / 0.4
spot size σ_x^*/σ_y^* [nm]	845 / 19	553 / 5
bunch length σ_z [mm]	0.7	0.4
beamstrahlung δ_B [%]	2.5	2.8
Disruption D_y	17	33
P_{AC} (2 linacs) [MW]	95	95
efficiency $\eta_{AC \to b}$ [%]	17	23
luminosity [10^{34} cm^{-2}s^{-1}]	0.68	3

Benefit from "superstructure"

25 MV/m → 21.7 MV/m

allows for Q= $5\ 10^{9} \rightarrow 10^{10}$

These values are at hand already

Both effects lead to a reduction of required cryo power

Invested in the beam power

→ Lower loaded Q → shorter filling time of the cavities

→ Higher conversion efficiency for mains to beam power

17% → 23%

Energy upgrade potential

With new "superstructure" concept the gradient needed for 800 GeV cm energy is 34 MV/m

From results of cavity R&D the optimism, that average gradients well above 30 MV/m @ Q-values of $5\ 10^{9}$ can be reached in the near future is justified

~~Most recent~~ BEST test in horizontal cryostat
33 MV/m @ $Q=4\ 10^{10}$

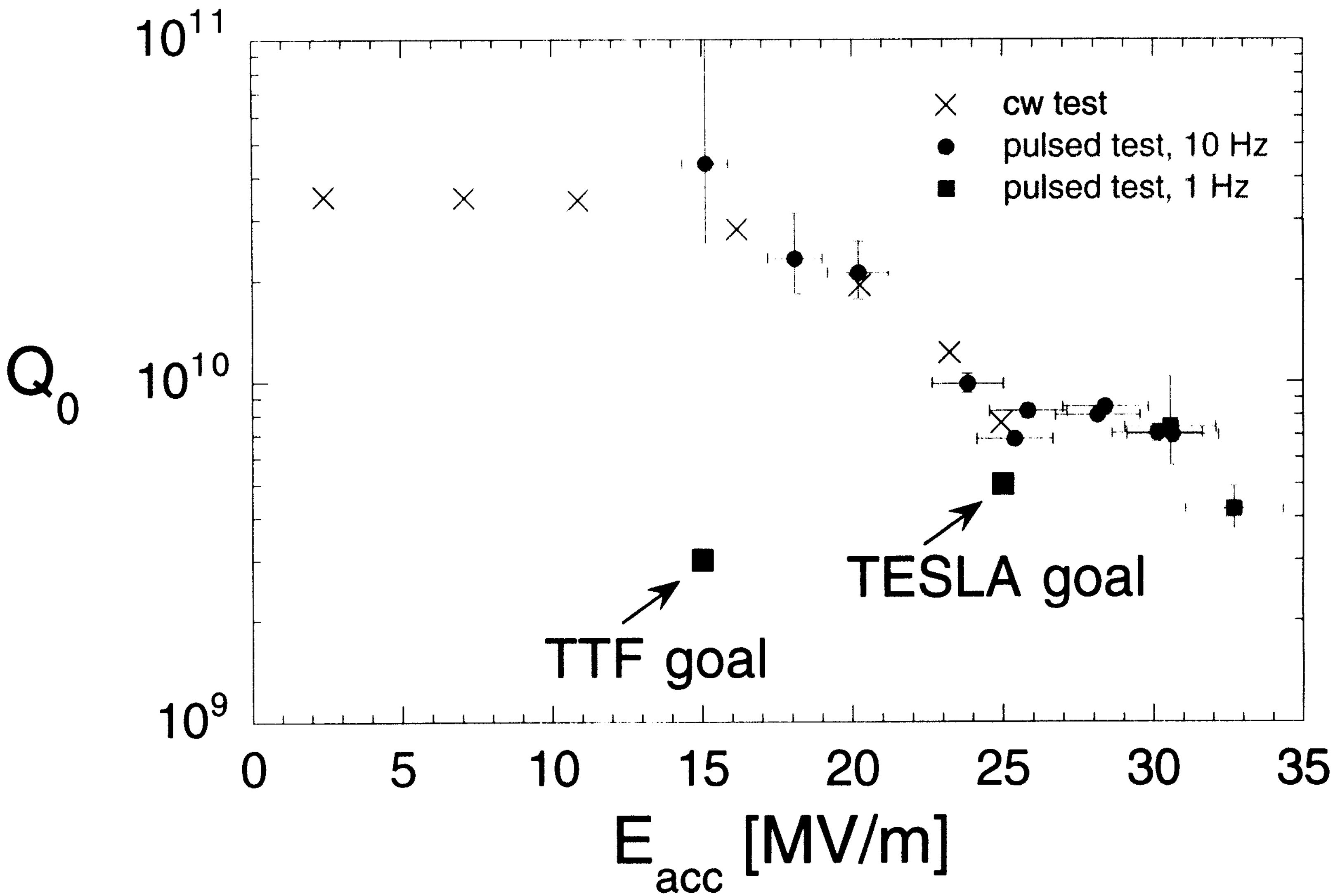
WITH STANDARD TREATMENT

At constant cryo power rep rate 5→ 3 Hz
vertical emittance reduced by factor 3

→ Luminosity $5\ 10^{34} cm^{-2} sec^{-1}$

Upgrade of cryogenic capacity → rep rate 5 Hz
→ Luminosity close to 10^{35} cm^{-2} sec^{-1}
can be achieved

Horizontal test result on cavity C23



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Bordesholm
Hohenwestedt
Aukrug
ITZEHOE
Hohenlockstedt
Kellinghusen
Bad Bramstedt
Holstein
Glückstadt
ELMSHORN
Barmstedt
Kaltenkirchen
Henstedt-Ulzburg
Quickborn
NORDERSTEDT
Uetersen
Tornesch
PINNEBERG
Rellingen
Halstenbek
Schenefeld
WEDEL
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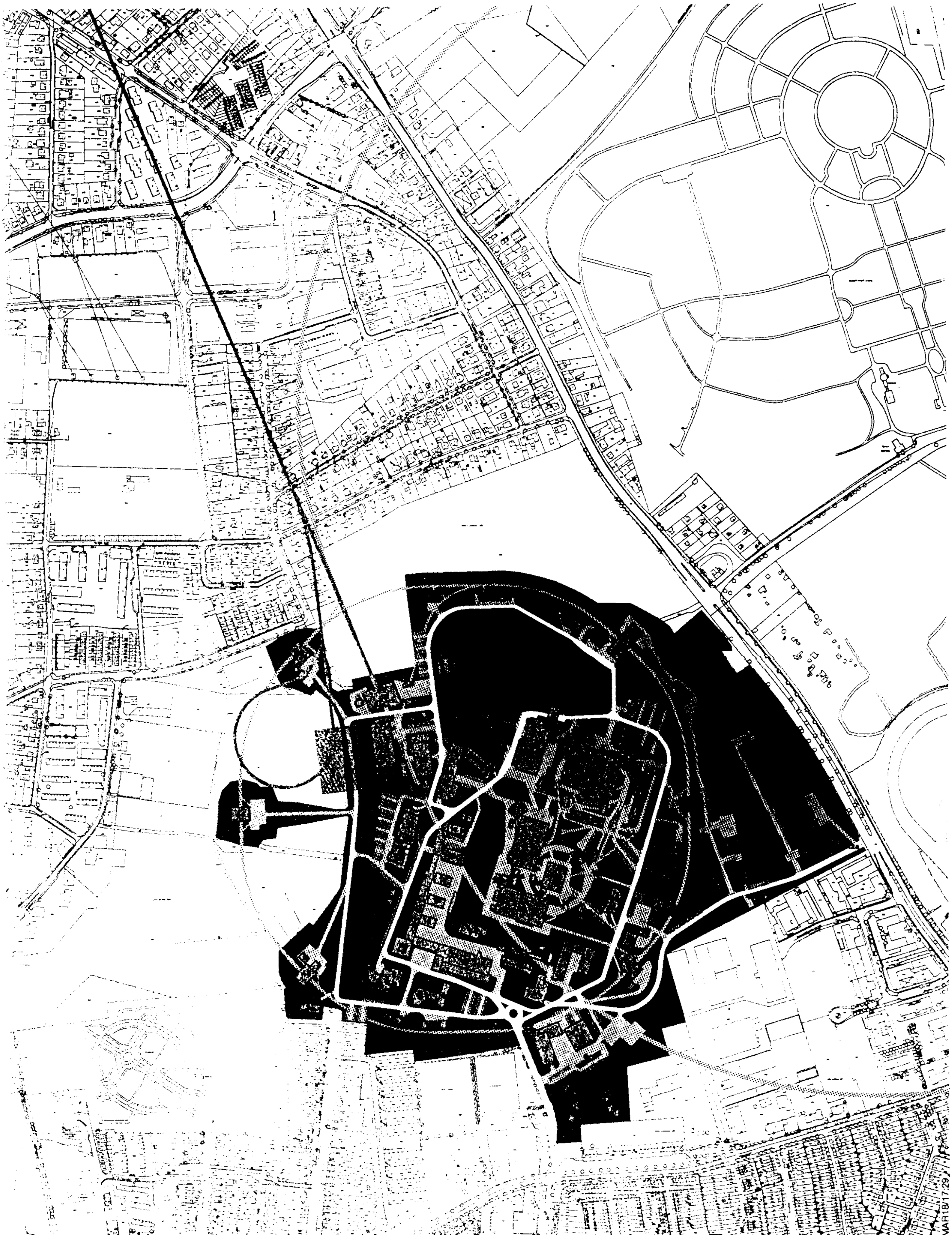
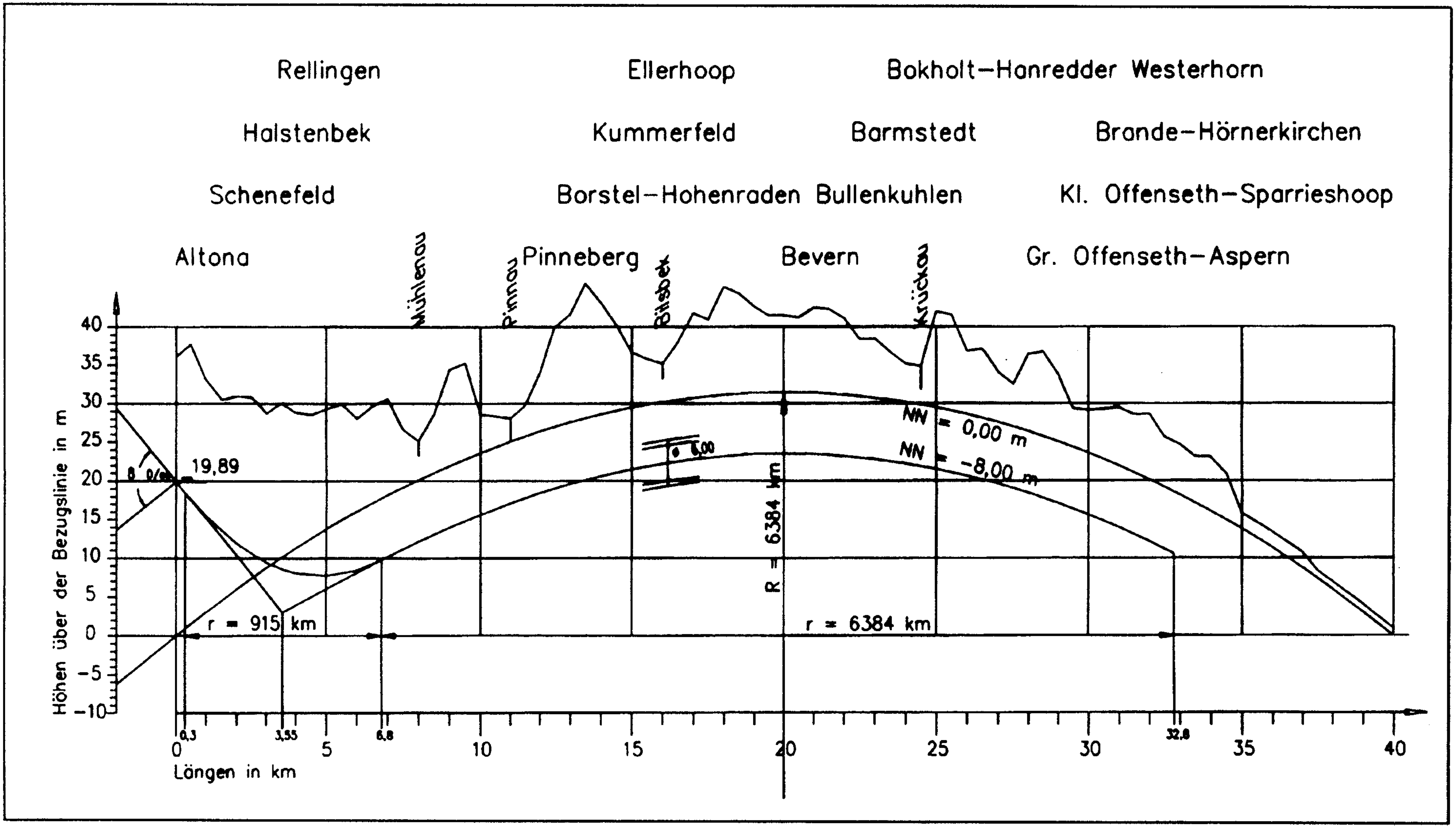
Finkenwerder
Altes Land





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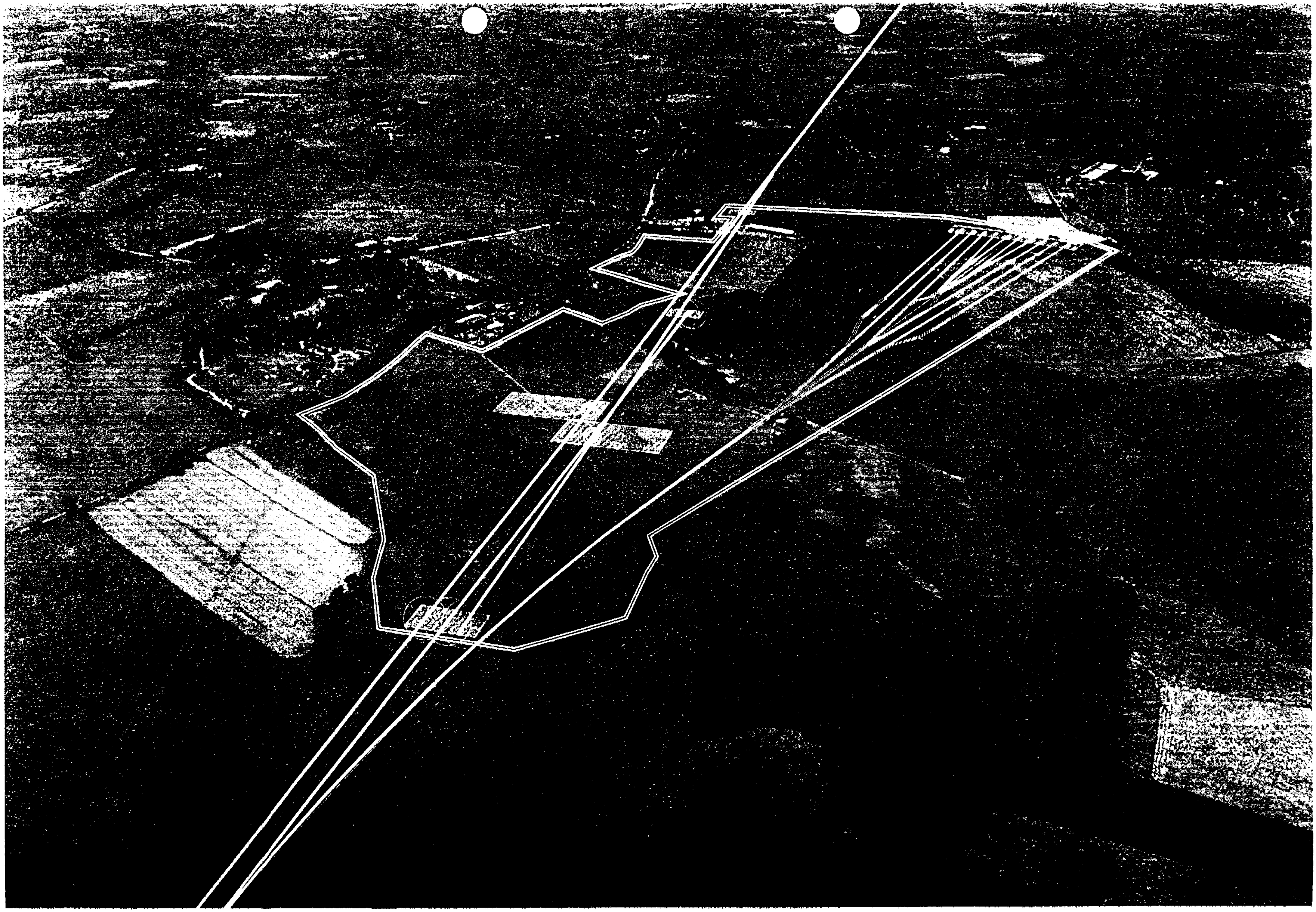
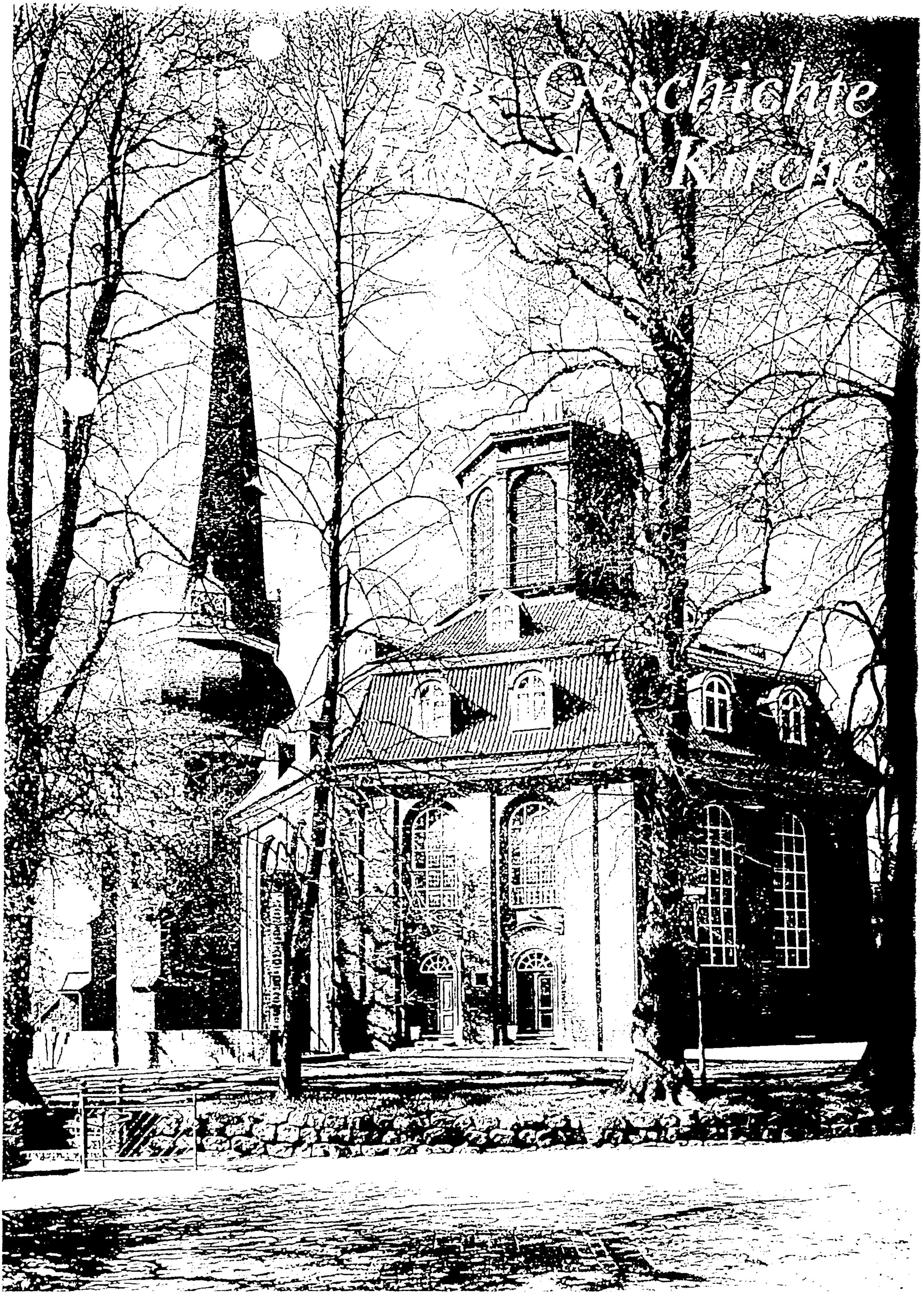
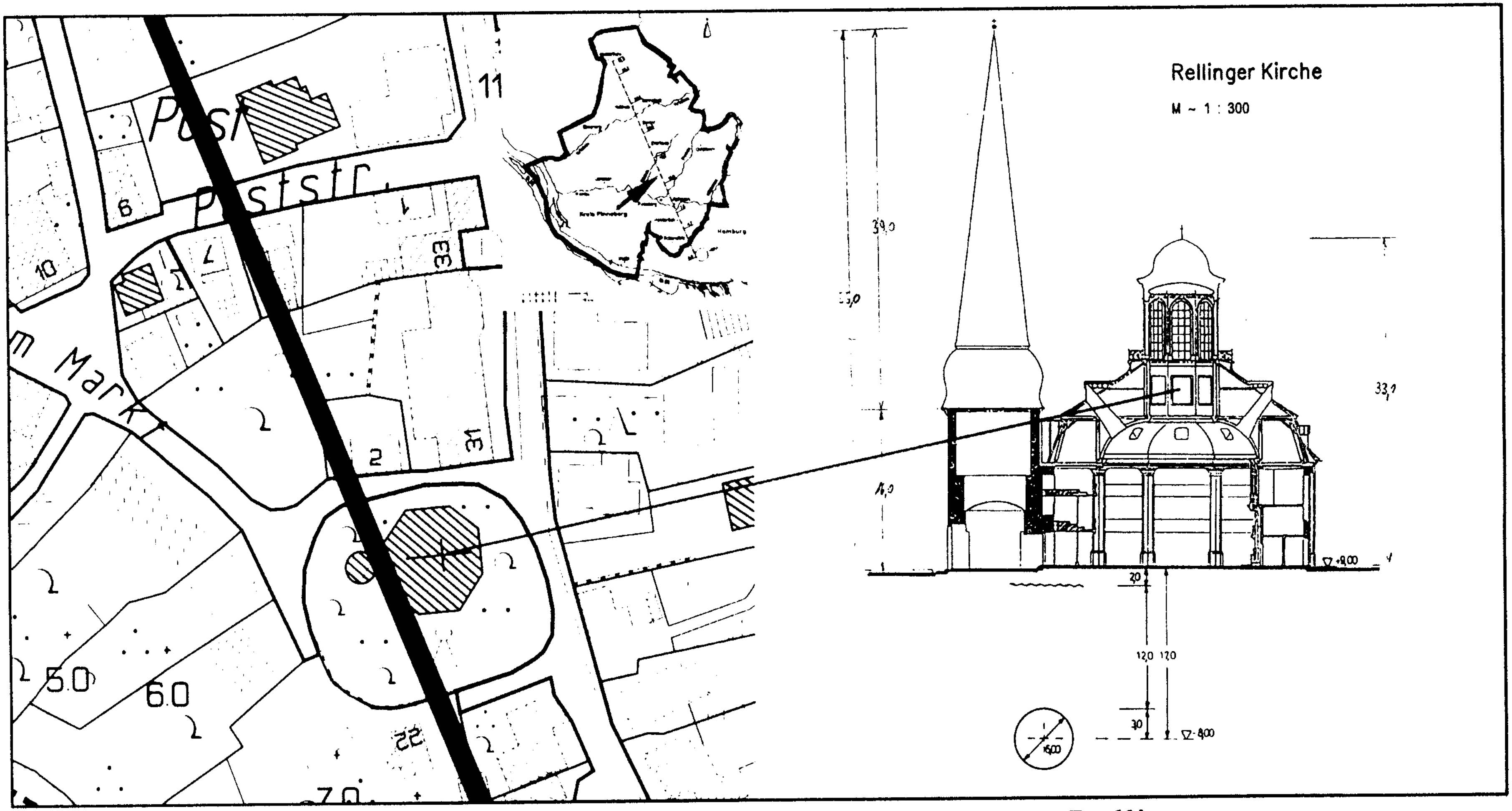



Geschichte
Kirche

Linear Collider

TESLA · Ein supraleitender Linear Collider mit integrierten Röntgenlasern bei DESY



Der Linear Collider Tunnel unter der Kirche von Rellingen.

I-DEAS Master Series 3: Design

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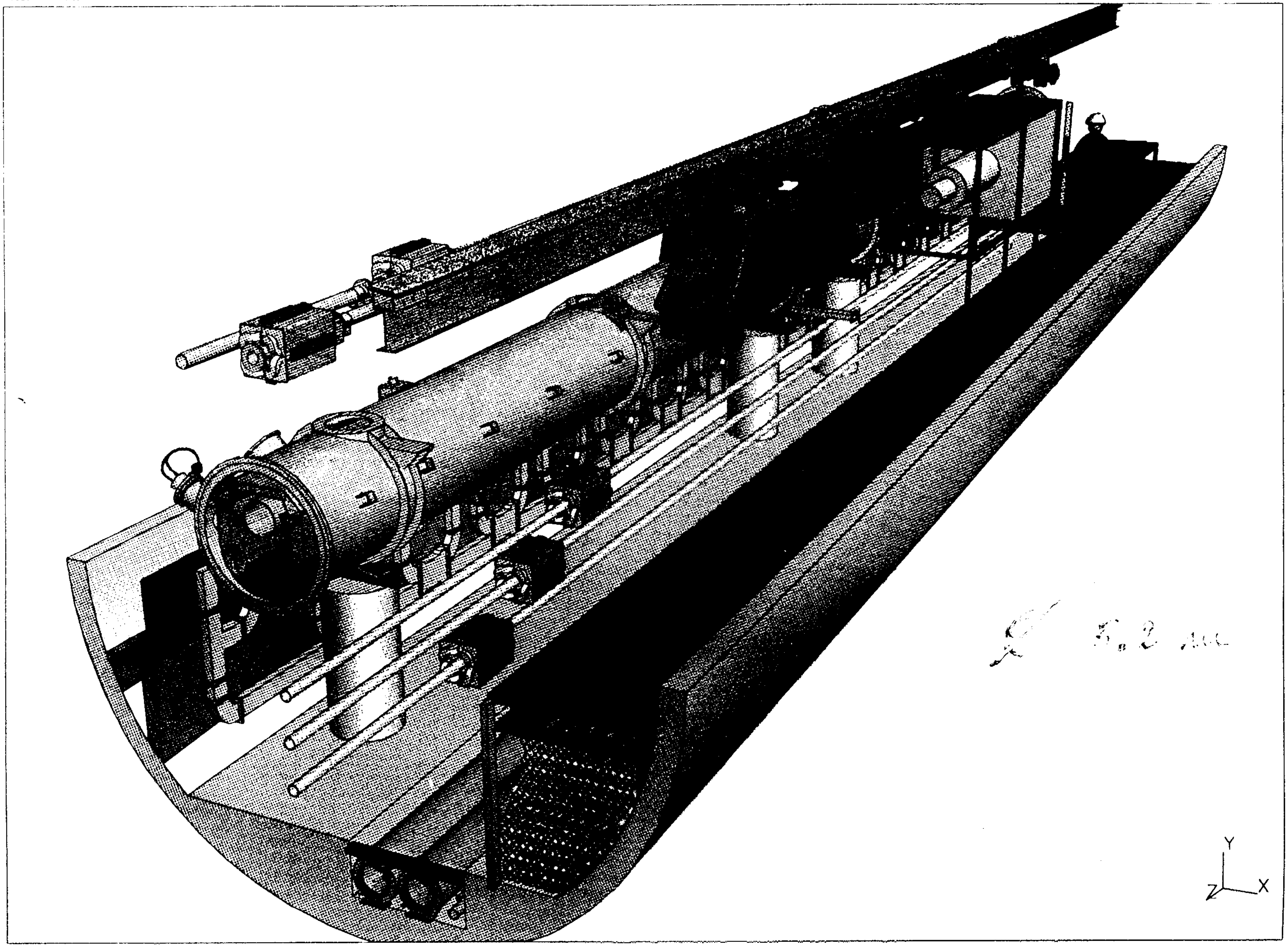

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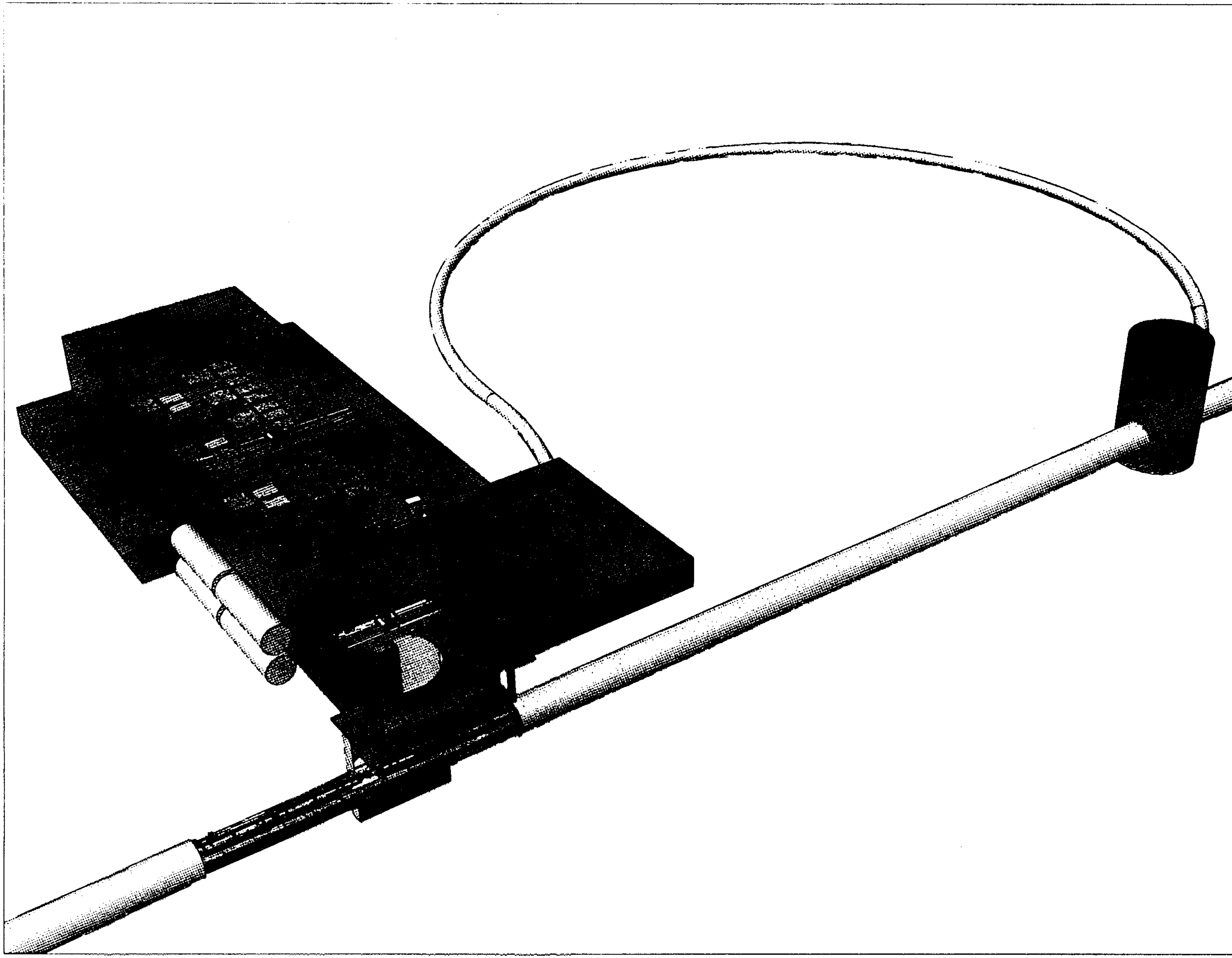
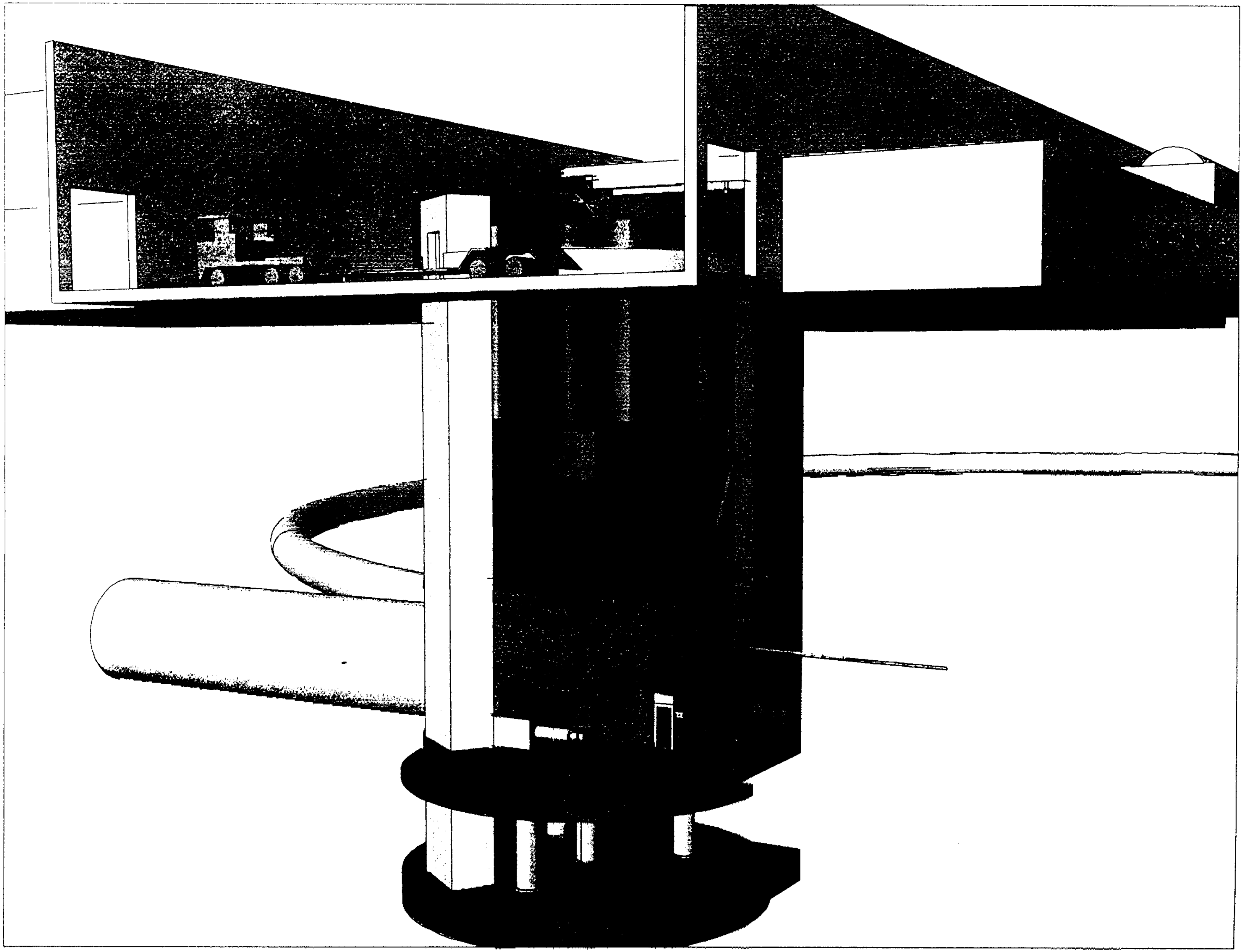




Want to have first cost evaluation of the whole project beginning of next year.

Also required manpower for the construction, installation and commissioning period.

INFN will design and evaluate
- damping rings
- cryostats
- cavity production

INR Troitsk will design and evaluate
- positron linacs

IHEP Protvino will design and evaluate
- beam dumps
- collimation system

Orsay/Saclay will design and evaluate
- injectors
- beam delivery sytem
- cavity production

Obtained results from two independent studies on cavity preparation to module assembly

Positiv: no problem to process 20000 cavities
within three years

Surprise: fraction of personnel to total cost
is dominant
main part therein module assembly

differences between two studies have to be evaluated

Studies underway or in preparation:

cavity production with present technology

parallel studies by INFN and Saclay are envisaged

klystron production

modulator fabrication

wave guide production

Road map

1998

treaty between Hamburg and Schleswig Holstein to jointly prepare legal conditions for the construction of TESLA

1999

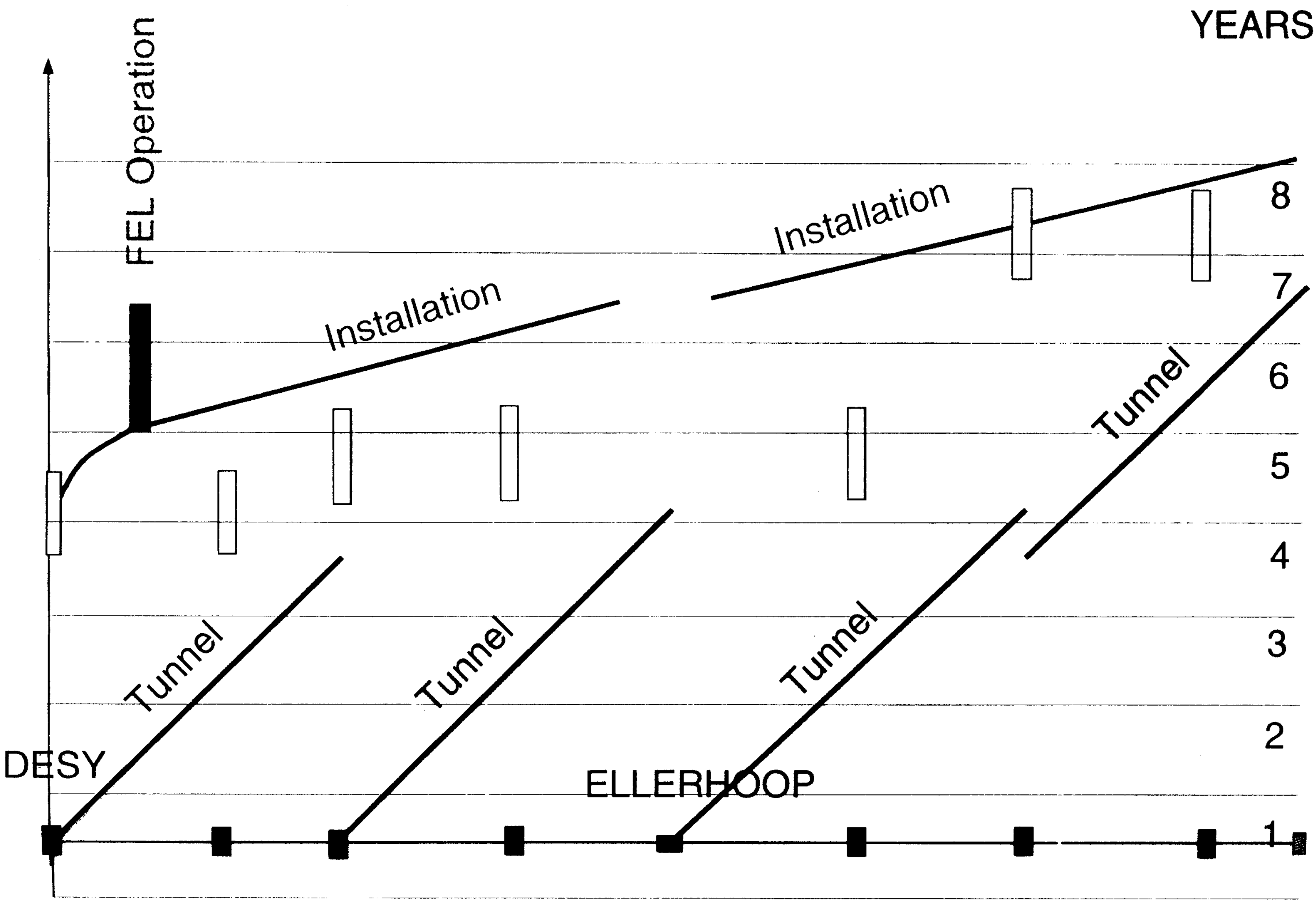
fixing of scope for environmental impact study
part of legal procedure

initiative to get evaluated by the German Science Council

2001

Technical design report including cost and schedule

Evaluation by Science Council


YEARS
FEL Operation
Installation
Installation
Tunnel
Tunnel
Tunnel
Tunnel
DESY
ELLERHOOP
1
2
3
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