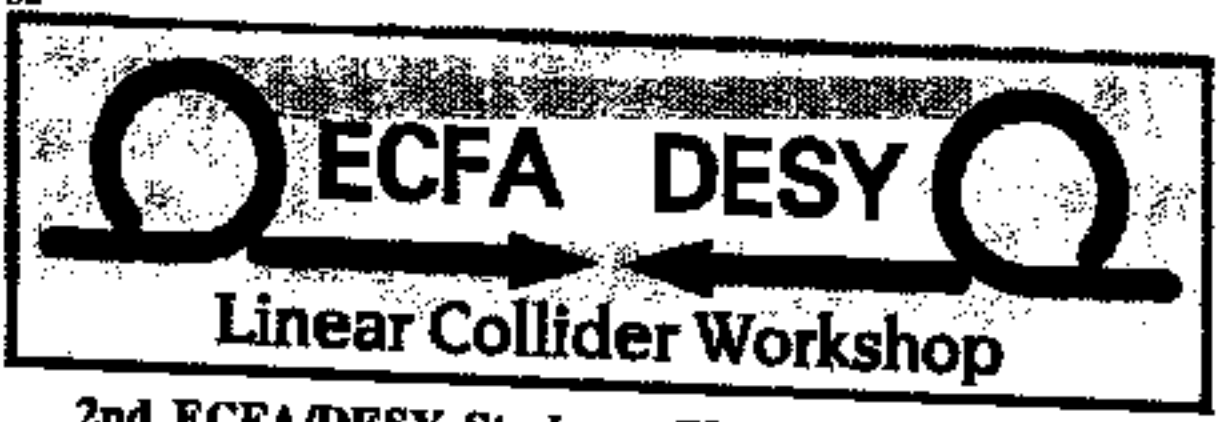
S2



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

LAL - Orsay - France, April 5-7, 1998

Date : April 5, 1998 - 14:10

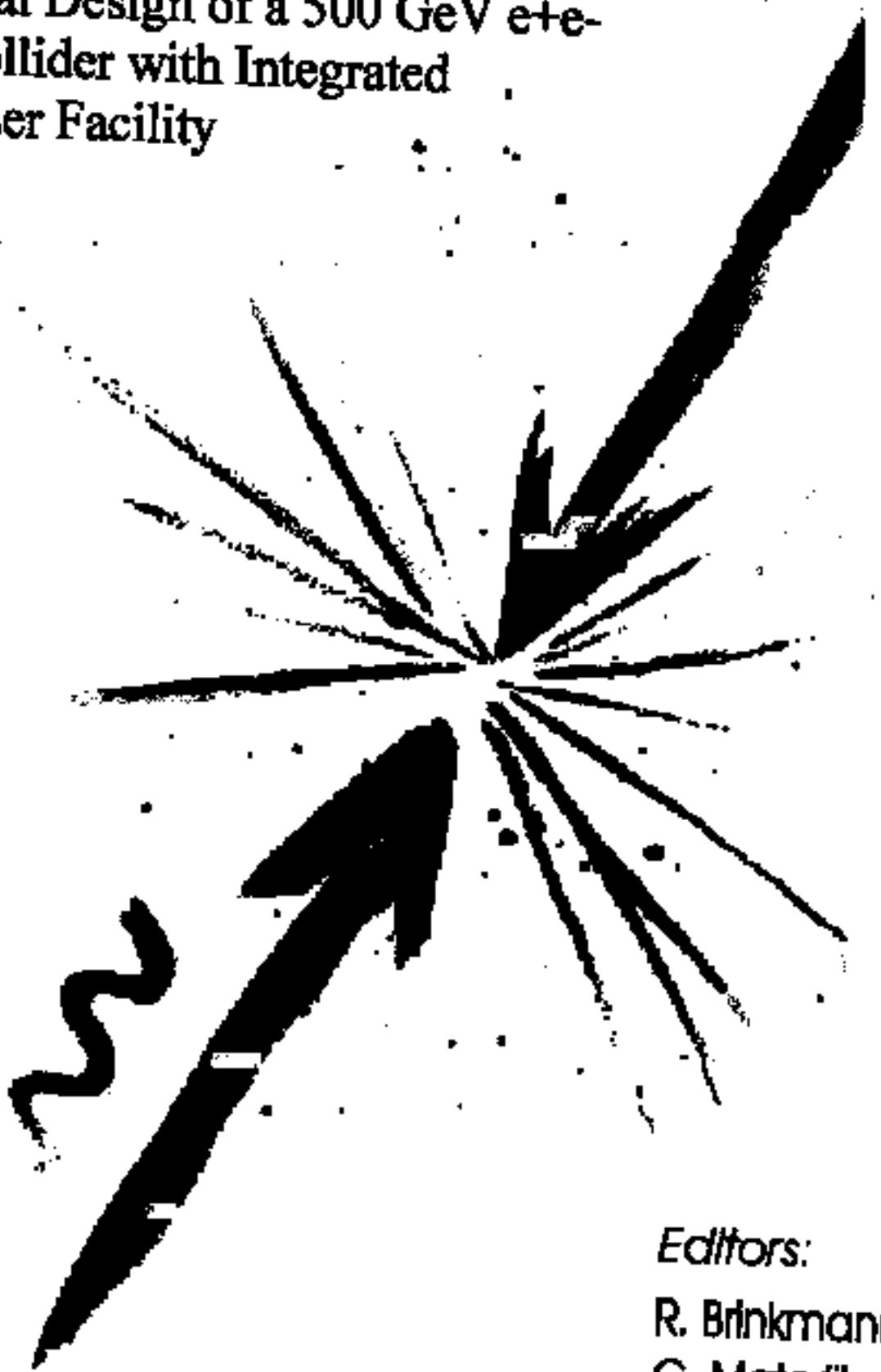
Speaker : B. Wiik

Strategic background

Talk by R. Brinkmann 2

Conceptual Design of a 500 GeV e+e- Linear Collider with Integrated X-ray Laser Facility

Volume I



Editors:

R. Brinkmann
G. Materlik
J. Rossbach
A. Wagner

DESY 1997-048
ECFA 1997-182

March : 1997

Conceptual Design Report of an e+e- Linear Collider with Integrated X-Ray Laser Facility

Completed in May 1997:

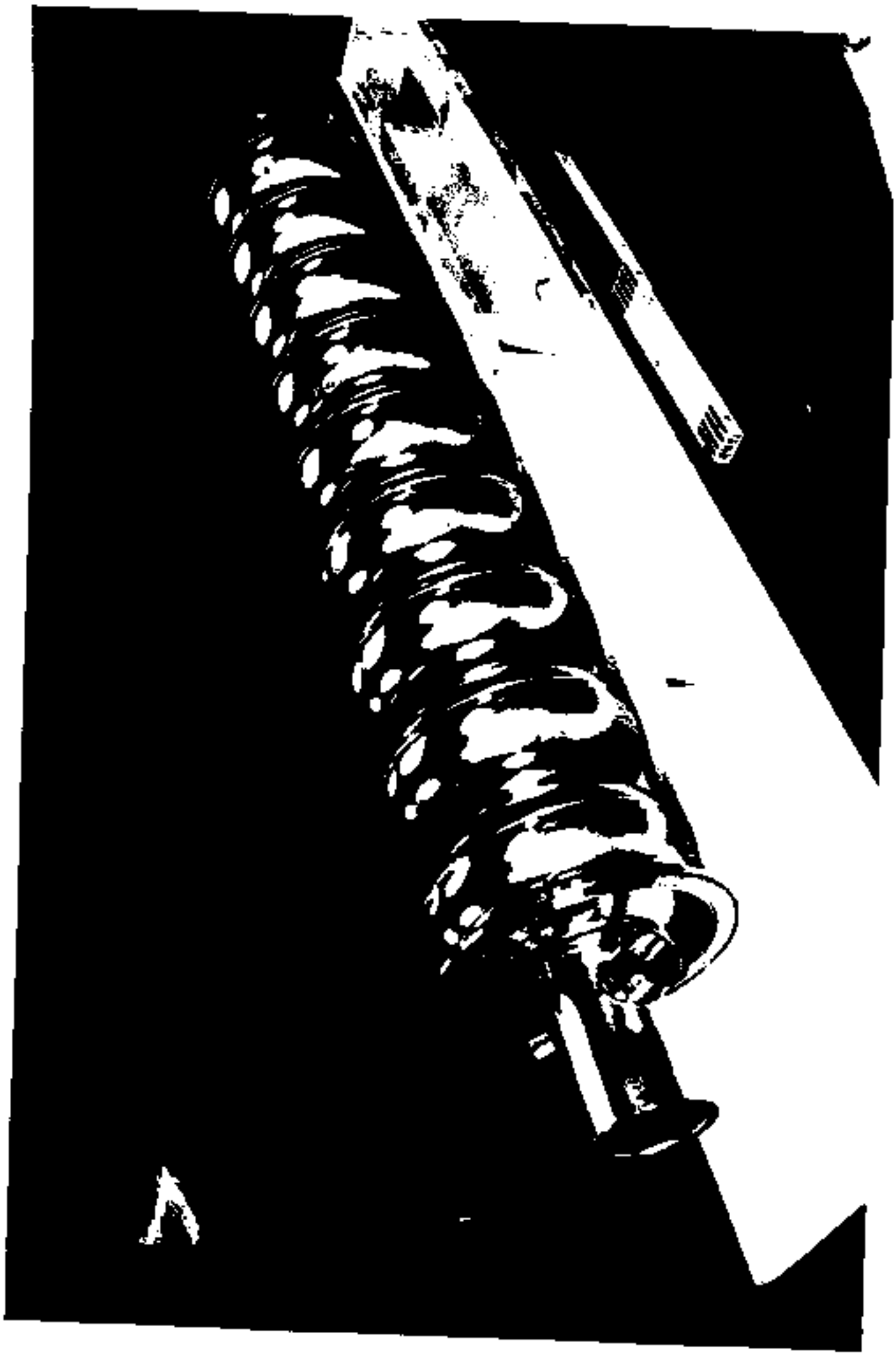
- **Particle Physics/ Detector for the Linear Collider**
  Joint ECFA (European Committee for Future Accelerators) and DESY study. 4 workshops (Frascati, London, Munich, Hamburg), about 200 participants each.

- **TESLA Linear Collider**
  Coordinated by DESY. 38 institutes from 10 countries.

- **S-Band Linear Collider**
  Coordinated by DESY. 18 institutes from 8 countries.

- **Superbrilliant X-Ray Laser Facility**
  59 authors, 18 institutes from 7 countries.

- **Appendix: An Electron Laboratory for Europe at DESY**
  NuPECC (Nuclear Physics Group of the European Science Foundation), 14 experts, 7 institutes from 4 countries together with DESY.

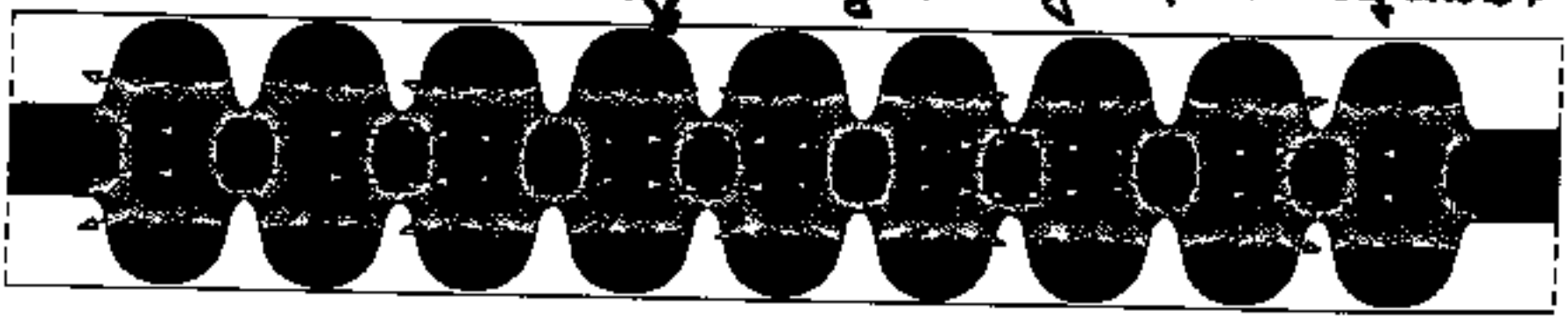


Wall loss : $\Delta W = \dfrac{E_{acc.}^2}{(r/Q) \cdot Q_0}$ ← Gradient

(r/Q) ← geom. Q_0 ← Quality factor

$Q_0^{s.c.} / Q_0^{N} \sim 10^6$

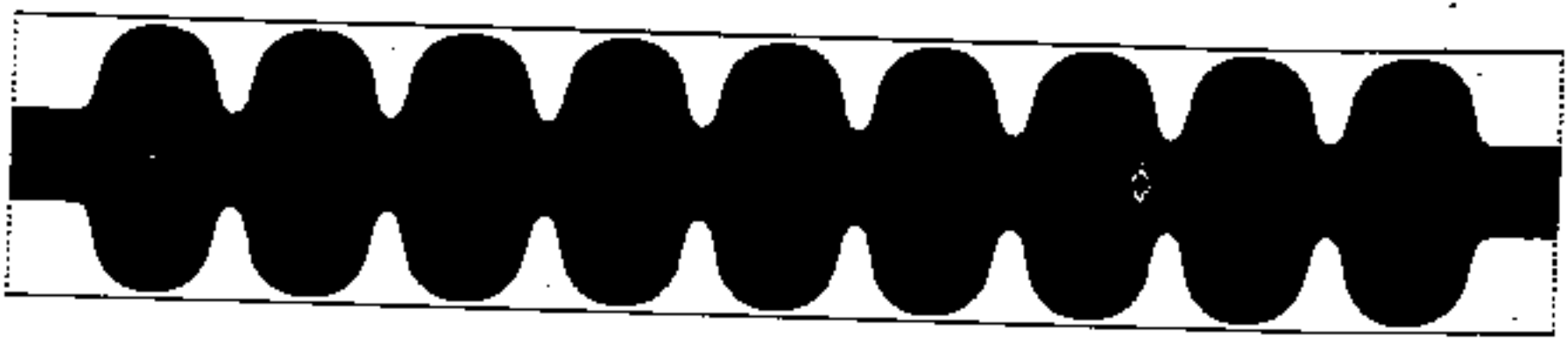
$E_{acc.}^{max} \sim 55$ MV/m Determined by the strength of the magnetic field at equator



- high eff. in converting mains power into beam power
- low rf frequency → "negligible" wall fields

$$\frac{d\varepsilon}{\varepsilon} = F \cdot \bar{\beta} \cdot (dy_c)^2$$

$$F(\text{TESLA}) \Big/ F(\text{X band}) \simeq 2 \cdot 10^{-4}$$



Tolerances

- Short range wakefields: (ω^6)
  → Tolerances on structure positioning

  TESLA: 500 μm Xband: 10 μm

  Long range wakefields:

  TESLA negligible influence

  X band → requires damped / detuned struct.

- Dispersive and chromatic effects:
  → Tolerances on quad. and bpm positioning

  TESLA: 100 μm

  X band: 1 - 3 μm

- Ground motion:

  δ_{yQ}: rms quad. displacement for $\Delta E/E \sim 10\%$

  TESLA: 2000 nm

  X band: 5 nm

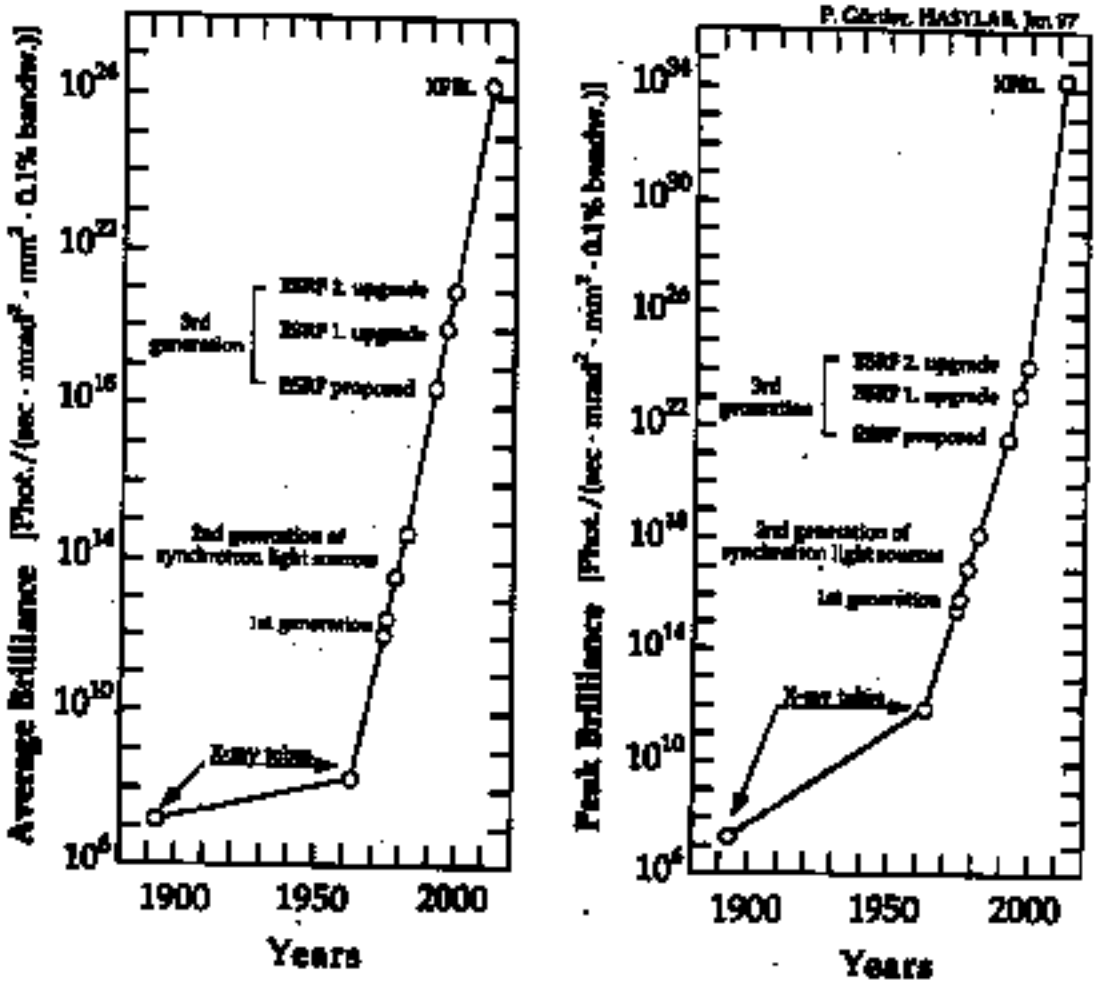
  T_c time between corrections assuming an ATL like ground motion:

  ($A = 4 \cdot 10^{-6}$ μm²/m/s)

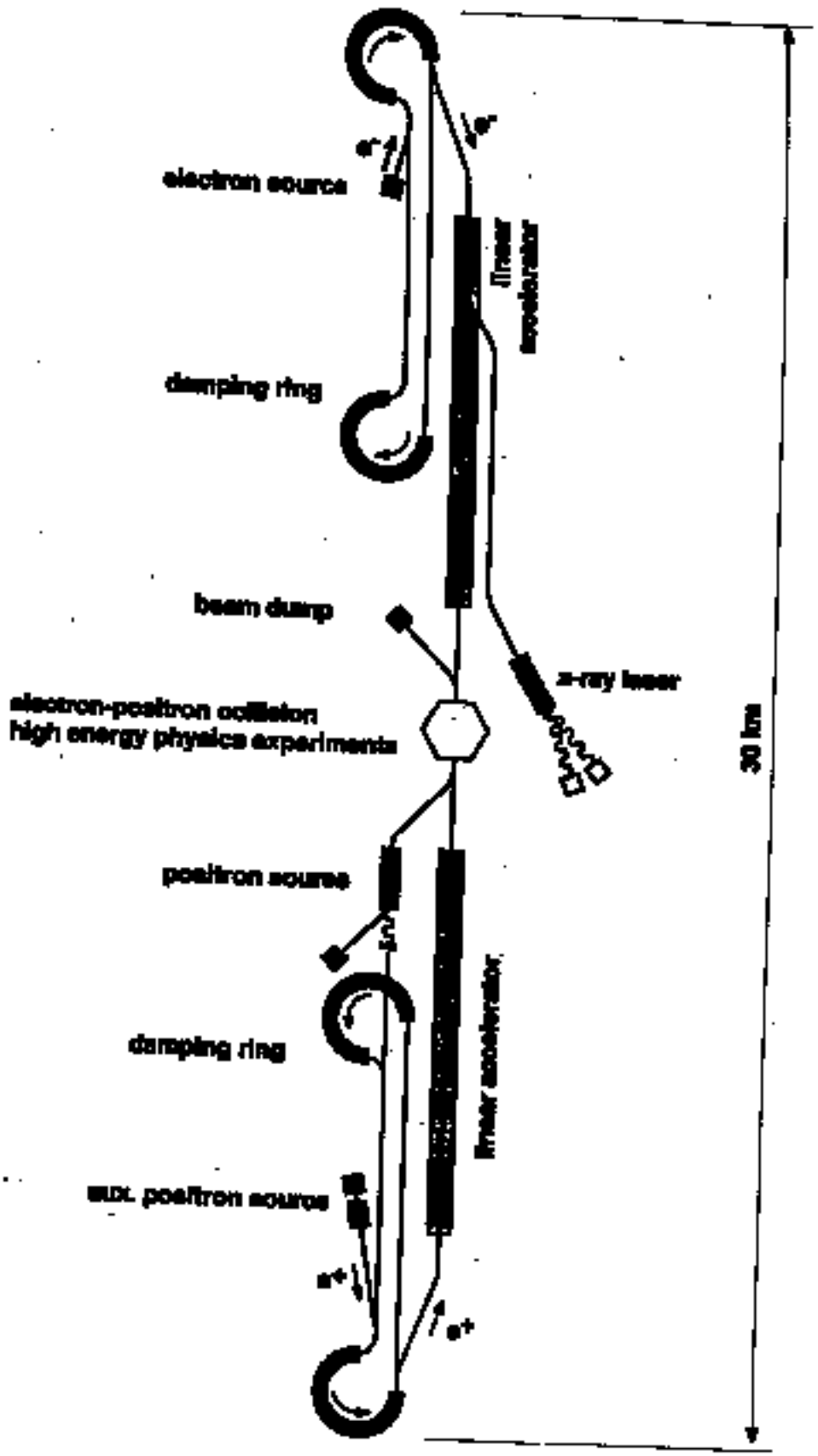
  TESLA: $1.6 \cdot 10^4$ s

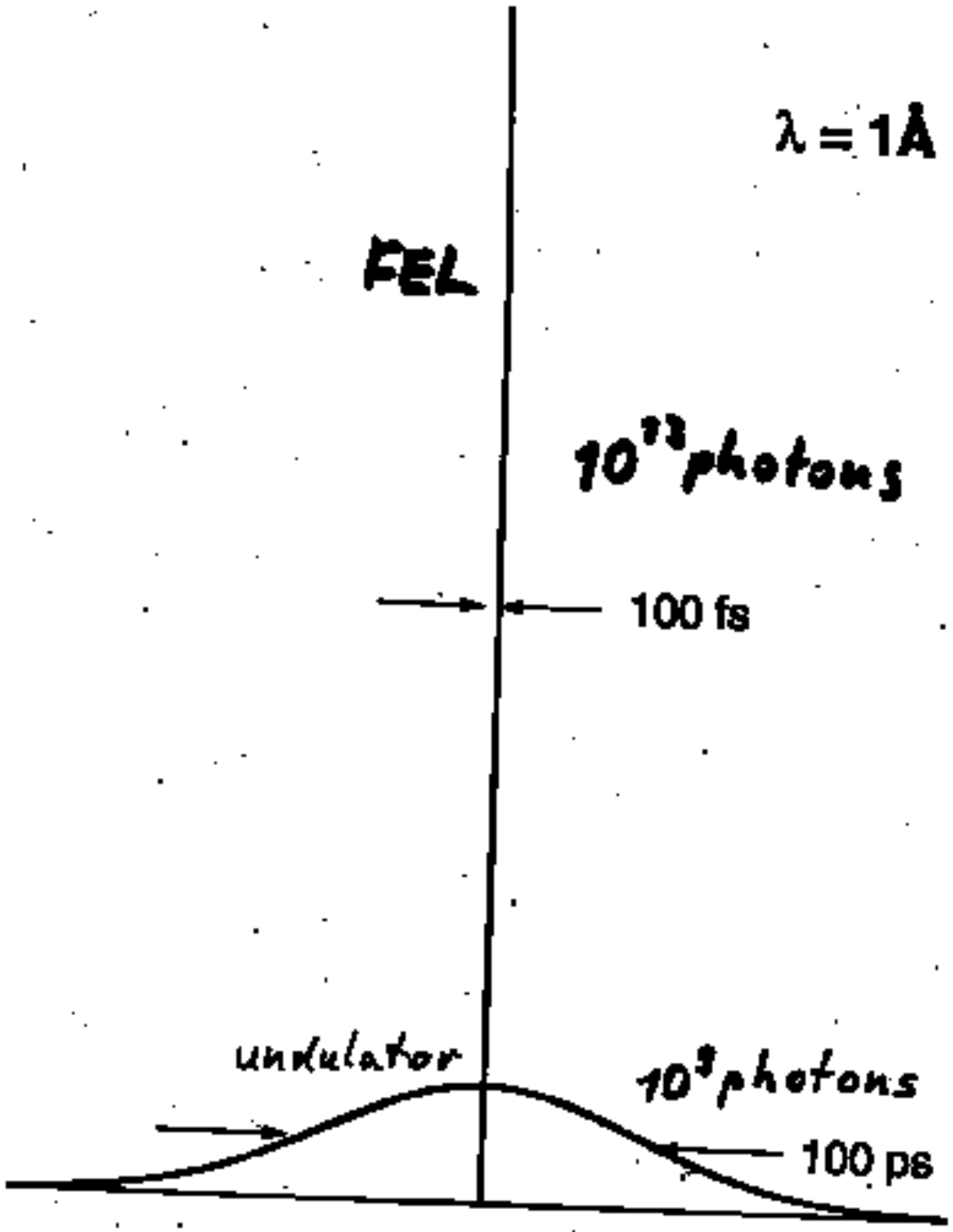
  X band: 0.25 s

Entwicklung der Röntgenquellen



	3rd Generation Sources	TESLA
Peak Brilliance	10^{24}	10^{34}
Average Brilliance	10^{21}	10^{28}
Time Resolution	50 ps	100 fs
Transverse Coherence	10^{-6}	1


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


λ = 1Å
FEL
10^{12} photons
100 fs
undulator
10^{9} photons
100 ps

EMBL

European Molecular Biology Laboratory

20 years on

1974-1994

EMBL's Service to Europe Began at Hamburg

More than twenty years ago, the EMBL project introduced the use of synchrotron radiation for the analysis of biological structures to the world. The first biological synchrotron radiation experiments by Ken Holmes, Gerd Rosenbaum and Juan Witz gave spectacular results, launching international biological interest in the use of these powerful X-rays. The source required for such radiation - in this case the Deutsches Elektronen-synchrotron (DESY) - was clearly unaffordable to normal laboratories and the planners of the EMBL project funded the early experiments to demonstrate the national benefits of European scientific cooperation. In 1975, EMBL formally agreed to coordinate the international use of DESY's radiation for molecular biology studies.

[redacted] DESY has proposed construction of a linear collider, as the next generation of particle accelerators, which would create unprecedented possibilities for biologists.

Extended Scientific Council
Linear Collider Review Committee

Introduction

The Extended Scientific Council (ESC) appointed at its meeting November 14,1996 a committee to review the "Conceptual Design Report (CDR) for a 500 GeV e^+e^- Collider with Integrated X-ray Laser Facility" (DESY 1997-048/ECFA 1997-182). Members of the Review Committee (RC) of the ESC are:

- for the accelerator aspects of the linearcollider and the X-ray laser:

K. Hübner (CERN-ESC), G. Mülhaupt (PSI-ESC), C. Pellegrini (UCLA), T. Raubenheimer (SLAC), A.N. Skrinsky (Novosibirsk-ESC), M. Tigner (Cornell), K. Takata (KEK), H. Winick (SLAC)

- for the particle physics and the detector aspect:

J. Dowell (Birmingham-ESC), F. Eisele (Heidelberg-ESC), J. Haïssinski (Orsay-ESC), E. Iarocci (Frascati), S. Komamiya (Tokyo Univ.), E. Lohrmann (Hamburg-ESC), L. Okun (Moscow-ESC) D. Wegener (Dortmund-ESC)

- for the aspect of synchrotron radiation:

M. Blume (BNL-ESC), K.C. Holmes (MPI-Heidelberg), B. Lengeler (Aachen-ESC), G. Schmahl (Göttingen-ESC).

Questions

- Does it make sense to combine an e+e- - collider and an X-ray radiation source?

  To realize an X-ray laser in the Ångström-region requires multi-GeV eletron beams of unprecedented quality. Furthermore, a large and welltrained staff is needed to construct, commission and operate the facility and a large site is required to produce, handle and use the intense photon beams. Thus combining the laser facility with the e+e- - collider facility will lead to a substantial reduction both in construction and operation cost.

  SLAC : 1300 Staff $E \sim 30$ GeV

- Can both programmes be carried out with minimum interference?

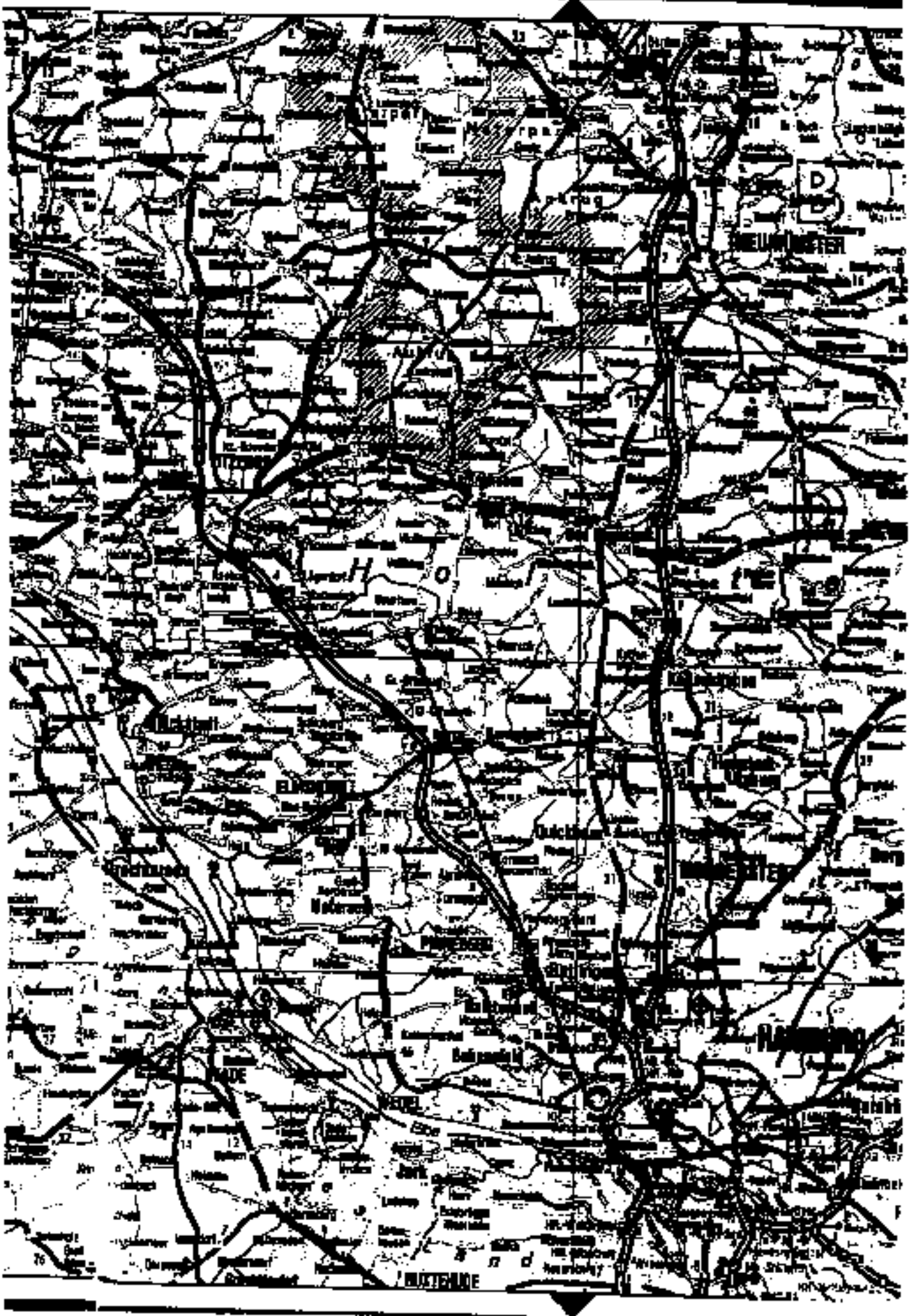
  e+e- duly cycle $\leq 1\%$. Undulators / beam lines on the surface.

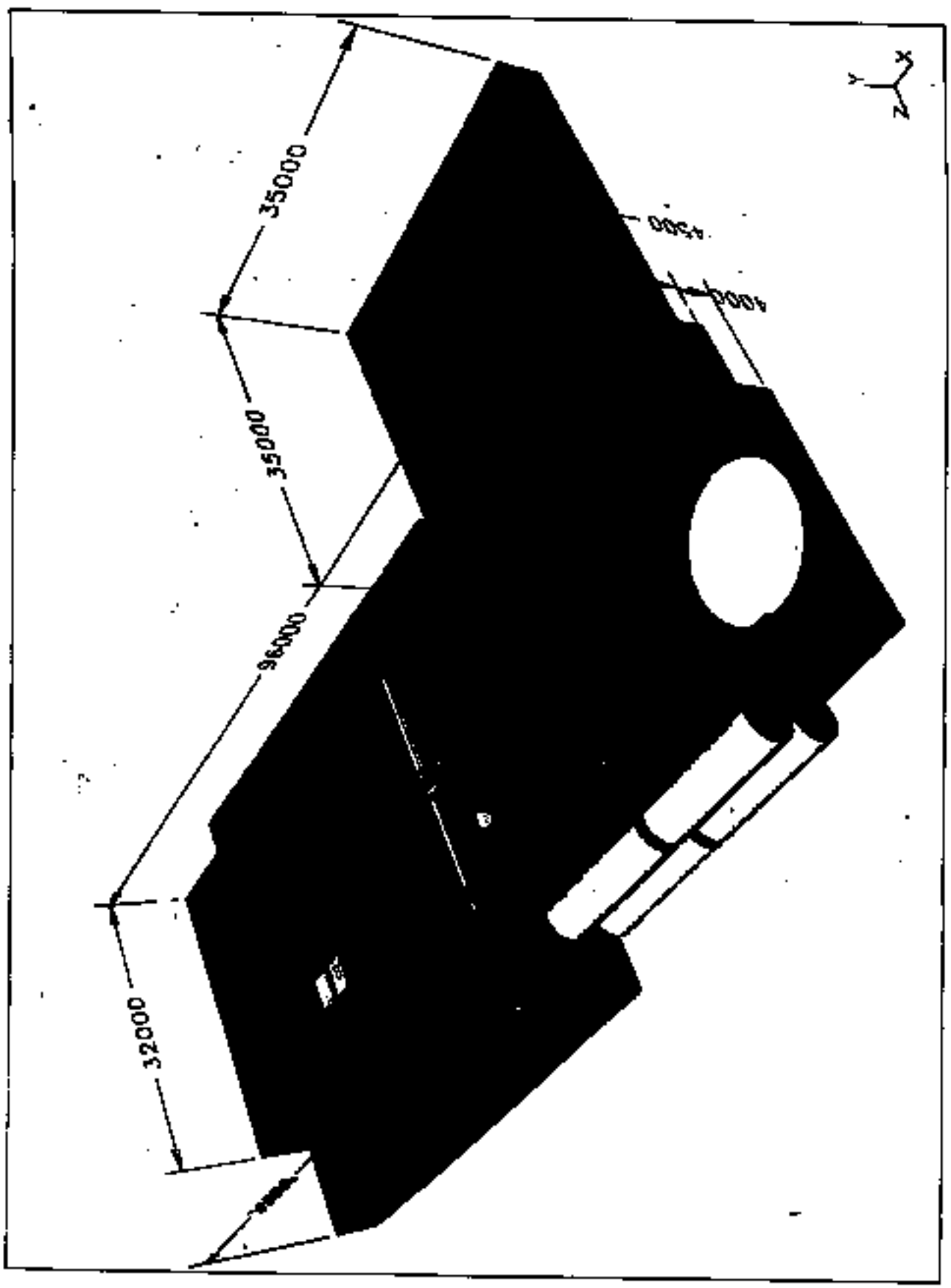
Considering the written report (as attached) of the review committee set up by the Extended Scientific Council (ESC) to evaluate the Conceptual Design Report (CDR) and short presentations by the coordinators of the working groups (Linear collider and X-ray source, particle physics and detector, synchrotron radiation application), the ESC discussed the project and arrived at the following conclusions:

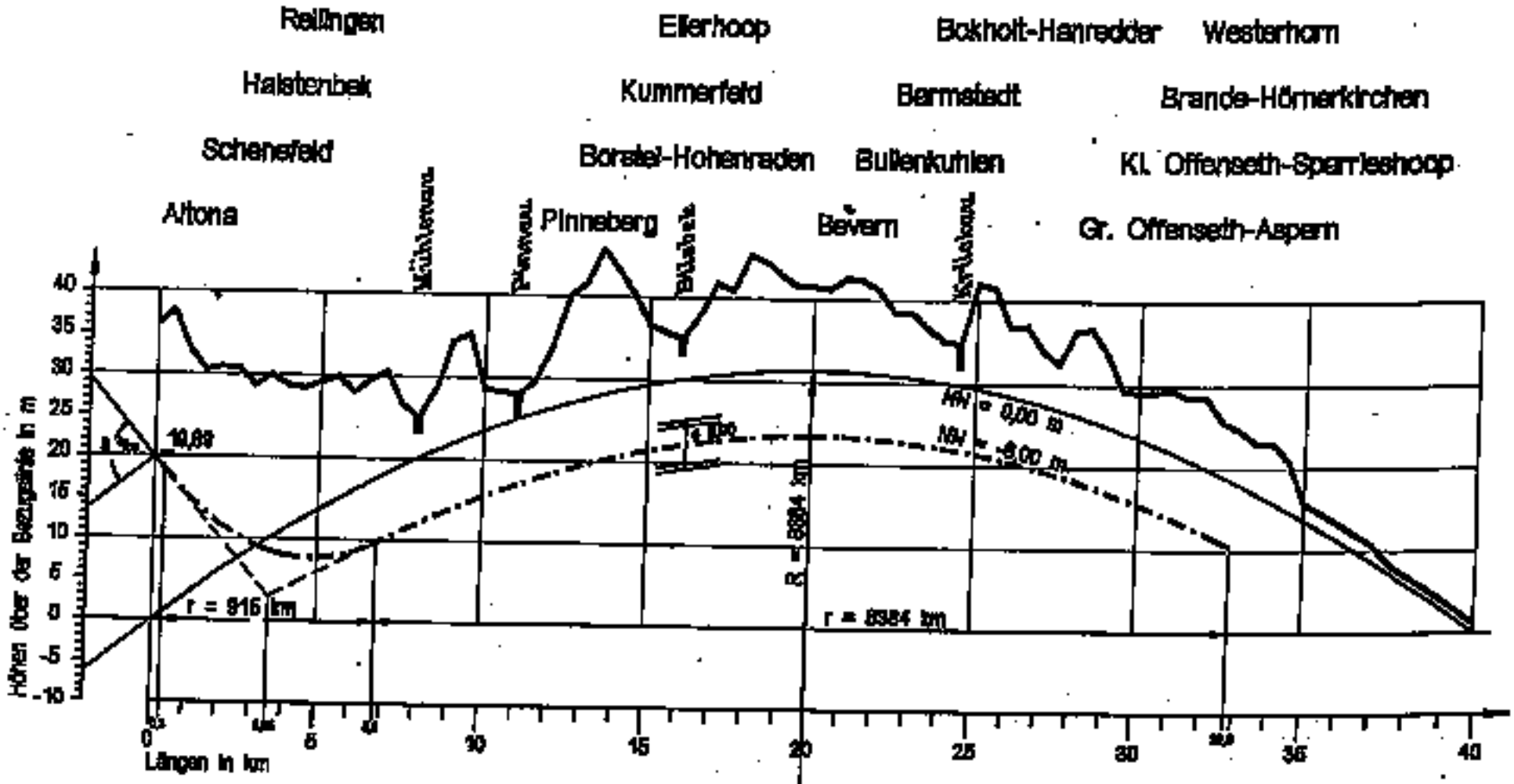
1. Based on the extensive world wide experience with building and operating high energy accelerator facilities and the R+D performed and planned by the DESY-group and its partners, the ESC feels there is every reason to believe that the performance goals outlined in the CDR can be met, despite the demanding technical challenges that face the accelerator team and, eventually, the industrial partners.

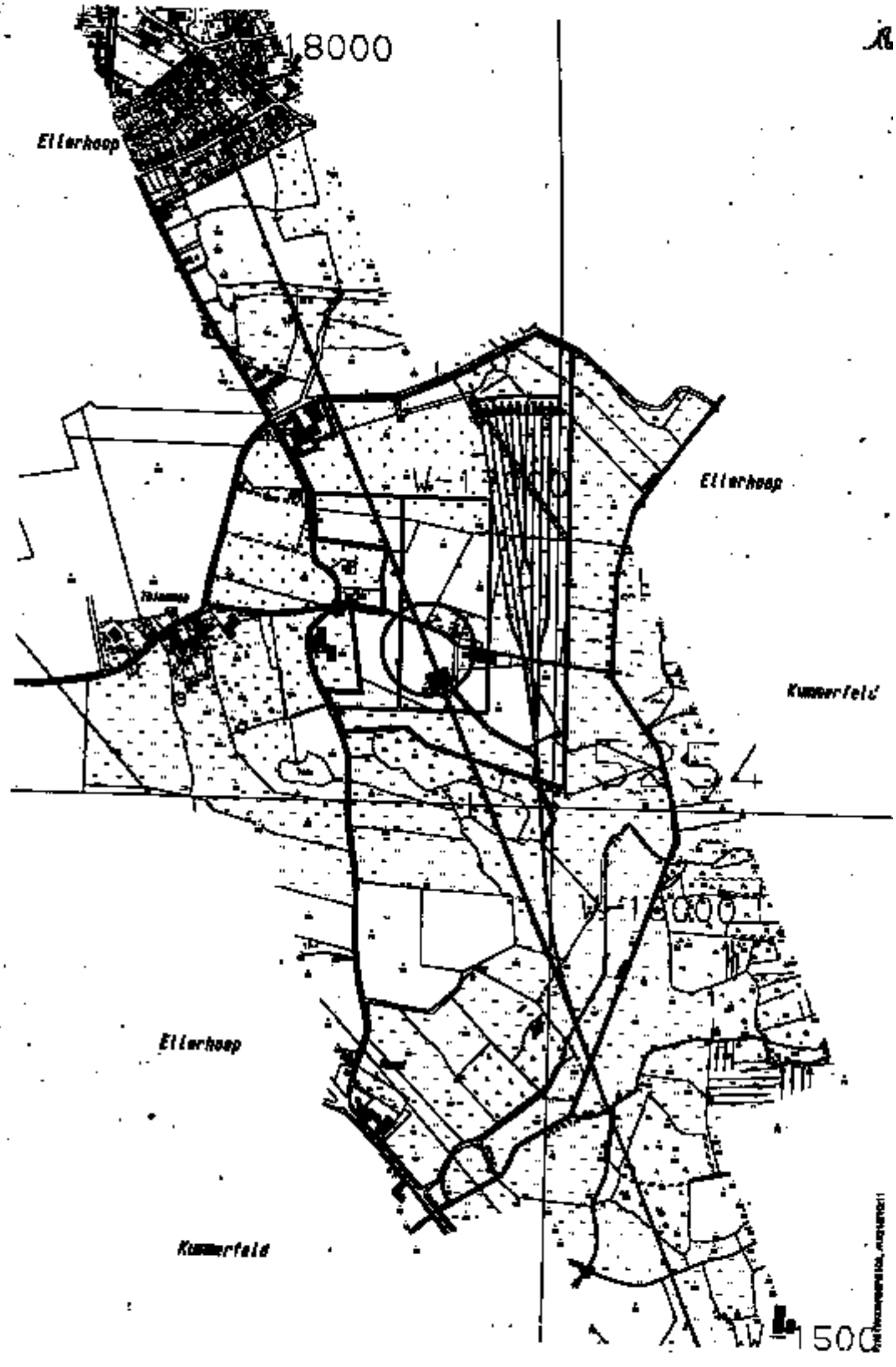
2. The organisational structure proposed for the international cooperation in building and running the linear collider facility seems to be feasable. The ESC encourages DESY to explore this line in more detail.

3. The electron-positron linear collider with an integrated X-ray source as outlined in the CDR is the project DESY should base its longterm future on.


Hamburg
Altona
Harburg
Wilhelmsburg
Bergedorf
Billstedt
Barmbek
Eimsbüttel
Winterhude
Eppendorf
Uhlenhorst
Hohenfelde
Rothenburgsort
Hammerbrook
Hamm
Horn
Billbrook
Billwerder
Moorfleet
Tatenberg
Neuengamme
Kirchwerder
Curslack
Altengamme
Reitbrook
Allermöhe
Neuallermöhe
Ochsenwerder
Spadenland
Moorwerder
Finkenwerder
Waltershof
Neuhof
Steinwerder
Kleiner Grasbrook
Veddel
Rothenburgsort
Hammerbrook


35000
35000
96000
32000
1300
1000
Y
X
Z


Reiflingen
Halstenbek
Schenefeld
Altona
Eidelstedt
Eidelstedt
Eidelstedt


18000
Etterhoop
Etterhoop
Kummerfeld
15000
Etterhoop
Kummerfeld
1500

Since the CDR

- it seems feasible to feed several cavities using a single power coupler

Sekutowicz

Filling factor: 67% → ~80%

Gradient needed to reach 500 GeV: 25 MV/m → ~21 MV/m

$$\mathcal{L} \sim \frac{\eta \cdot P_b}{E_{cm}} \cdot \frac{(\delta_B)^{1/2}}{(\varepsilon_y^N \cdot \xi)^{1/2}}$$

in a linear collider made from S.C. cavities the efficiency η for converting mains power into beam power is large and the emittance dilution ξ between source and I.P. is closer to 1 in a low frequency S.C. Linac than in a warm high frequency Linac

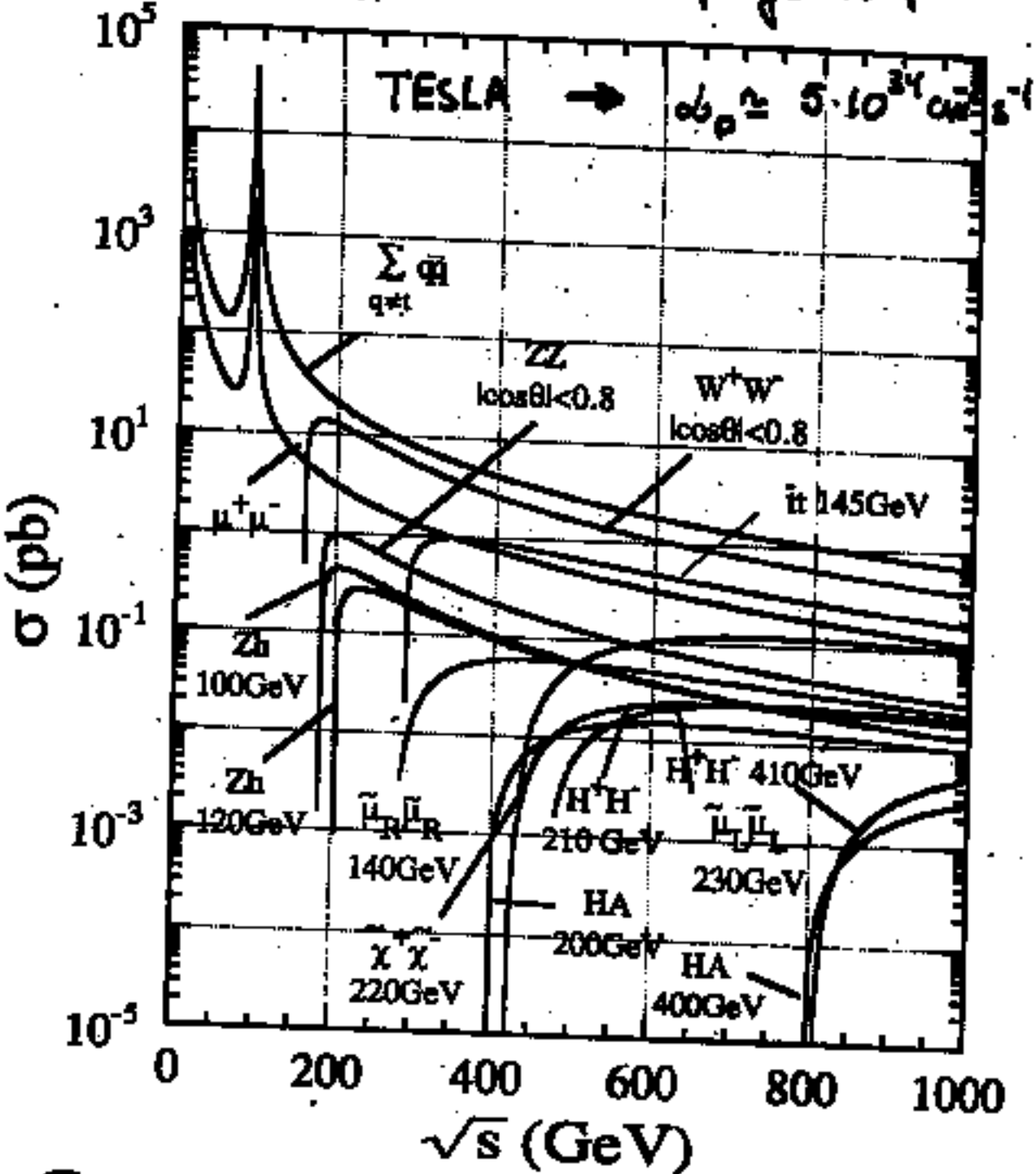
Hence one should be able to reach the highest luminosities with TESLA.

Brinkmann (TESLA 97-13): $5 \cdot 10^{33}\ cm^{-2}\ s^{-1} \longrightarrow 5 \cdot 10^{34}\ cm^{-2}\ s^{-1}$ with 100 MW and $\delta_B = 3 \cdot 10^{-2}$

ε_y^N (m·rad): $25 \cdot 10^{-8} \longrightarrow 0.75 \cdot 10^{-8}$

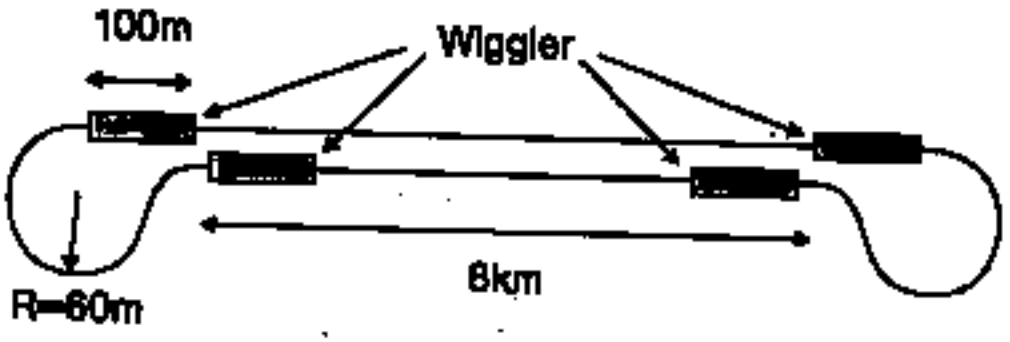
"Standard Physics"

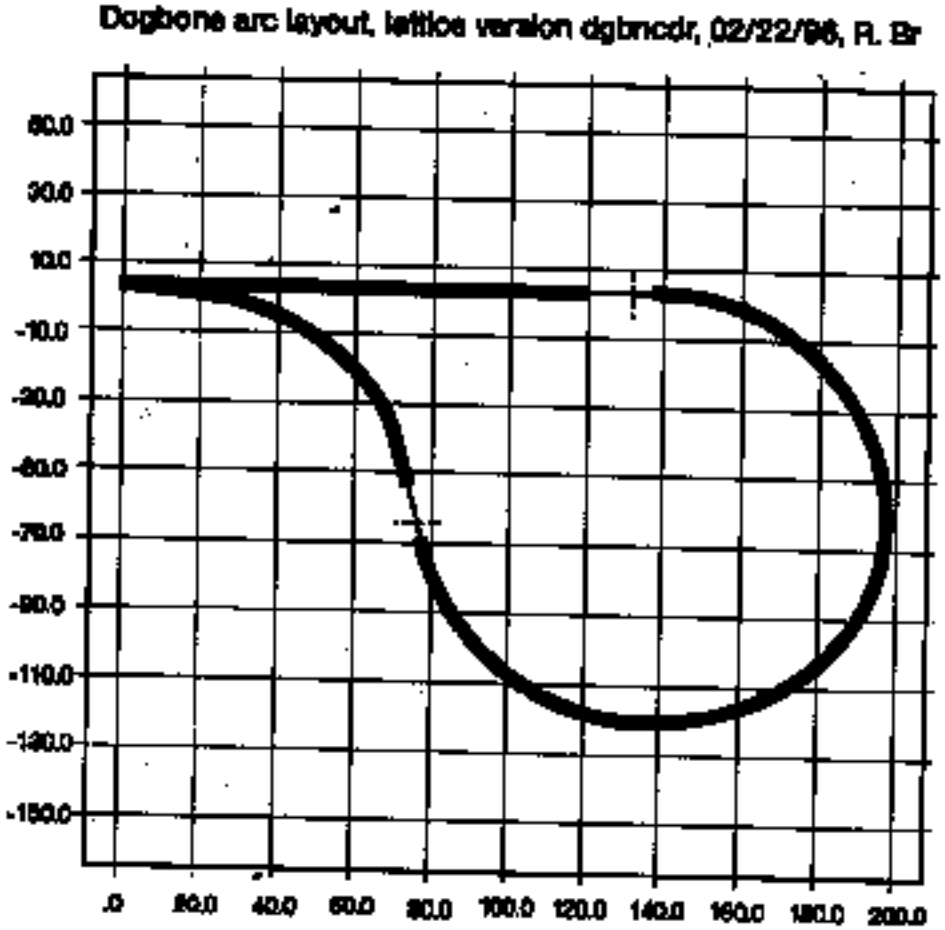
need an integrated luminosity of order 100 - 300 fb^{-1} year to exploit the physics



Final State		Events /300 fb^{-1}
$\sum q\bar{q}$		930 000
W^+W^-		$2.1 \cdot 10^6$
$t\bar{t}$	(m_t = 180 GeV)	240 000
ZH	(m_H = 120 GeV)	120 000

TESLA Damping Ring (E = 3.2 GeV)





The Frascati Group will be responsible for the design of the damping rings.

Agreement between
Istituto Nazionale di Fisica (INFN)

and

Deutsches Elektronen-Synchrotron DESY

on Cooperation in a Joint Effort

to Develop the Technological Base Needed to Construct a 500 GeV Linear Collider with an Integrated X-Ray Source
and
to Prepare the Proposal for the Full Size Facility.

Preamble

1. The study of electron-positron interactions has yielded fundamental information on the basic constituents of matter and the forces which act between these constituents.

   Experiments at a high energy e^+e^- collider facility will be crucial to the development of particle physics beyond the standard model and will be complementary to those carried out at the CERN large hadron collider LHC, and their results.

   The linear collider combined with the HERA electron ring has the potential for making important advances in nuclear physics.

- A linear collider based on superconductin low frequency cavities has advantages compared to a linac based on warm cavities

- but according to conventional wisdom: (1991)
  - low accelerating gradient: (5 MV/m)
  - costly
    200 k$/m of cavity
    → 40. k$/MV
  - difficult to operate

Goal of TESLA:

40 k$/MV → ≤ 2 k$/MV

demonstrate that a linac made using S.C. cavities is reliable

Members of the TESLA-Collaboration

IHEP
Academia Sinica, Beijing

Tsinghua-University, Beijing

SEFT
University of Helsinki

CEA/DSM
(DAPNIA, CE-Saclay)

IN2P3
(INP Orsay + LAL Orsay)

Max-Born-Institut,
Berlin-Adlershof

DESY, Hamburg und Zeuthen

GH Wuppertal
Fachbereich Physik

IAP, University of Frankfurt

GKSS, Geesthacht

FZ Karlsruhe

IfH, TH Darmstadt

ITE, TU Berlin

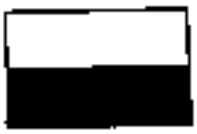
IKK, TU Dresden

RWTH Aachen III

INFN Frascati

INFN Milano

INFN Roma II



Polish Academy of Science
Warsaw (IF PAN)

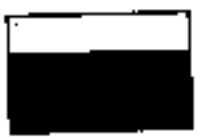
University of Warsaw,
Inst. of Exp. Physics

University of Cracow (INP)

Univ. of Mining & Metallurgy,
Cracow

Polish Atomic Energy
Agency, Cracow

Soltan Institute for Nuclear
Studies, Otwock-Swierk



JINR Dubna

IHEP Protvino

INP Novosibirsk

Cornell University
Newman Lab. Ithaca NY

Fermilab
Batavia IL

UCLA
Los Angeles CA

Contribution from Non-German Inst.
≈ 17 MDM. 330 M Years

DESY: 24 MDM.

Superconducting Cavities

The Road towards high Gradients

- Use very good heat conductivity pure Nb
  RRR ~ 300 - 500 (O_2, Ta)
- Extreme cleanliness in cavity handling
  (clean room class 10)
  Ultra pure chemicals
- Rinsing with ultrapure water at ~ 200 bar
- High Temperature Annealing:
  Process the cavities at T ~ 1500° C in a
  10^{-7} torr Ti-atmosphere
- High Peak Power Processing:
  Process the cavities with ms long RF pulses
  at the MW level

$$RRR = \frac{\text{Conductivity of Nb at} \sim 10K}{\text{Conductivity at } 300K}$$

RRR is a measure of the purity of the material.

TESLA Test Facility

- **Develop the technological base for a 500 GeV superconducting Linear Collider by 2000**

- **Design, build and test multicavity modules with:**

  Nb - 9 cell cavities }

  Cost: 50 k$ / m
  Gradient: 15 → 25 MV / m
  Q-value: 3×10^9 → 5×10^9
  Static heat load: < 1 W / m

- **Build and operate a 400 MeV linear accelerator made of prototype s.c. multicavity structures**

- **Demonstrate the SASE Principle for short wavelengths (~400 Å)**

  Low emittance RF gun
  Longitudinal bunch compressor
  Undulator
  Diagnostics

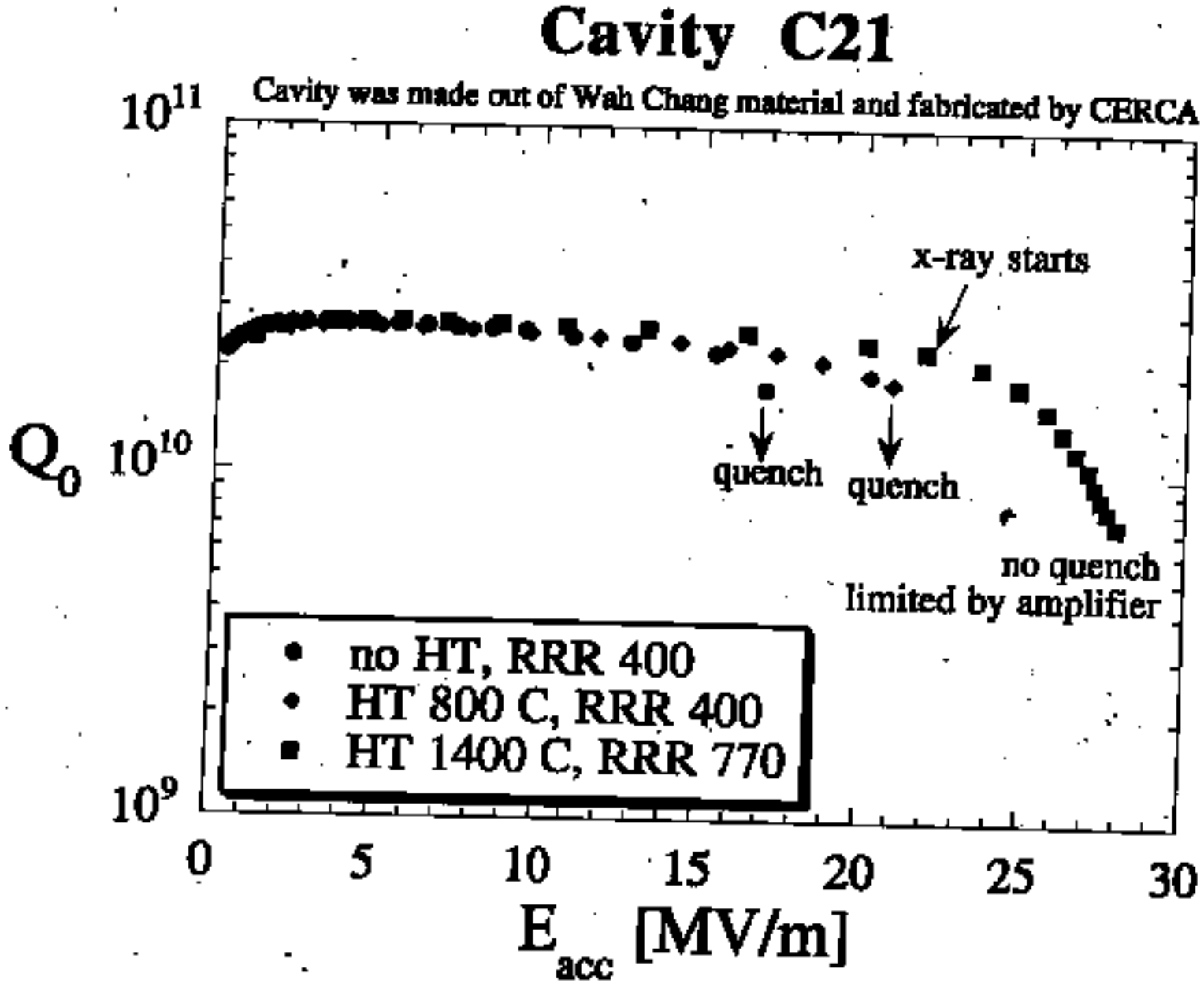
- **Increase the linac energy to > 1 GeV by adding 5 to 7 more modules and construct a SASE FEL User Facility in the VUV regime with wavelengths in the range from 10 nm to 3 nm**

The Steps (defined in 1992)

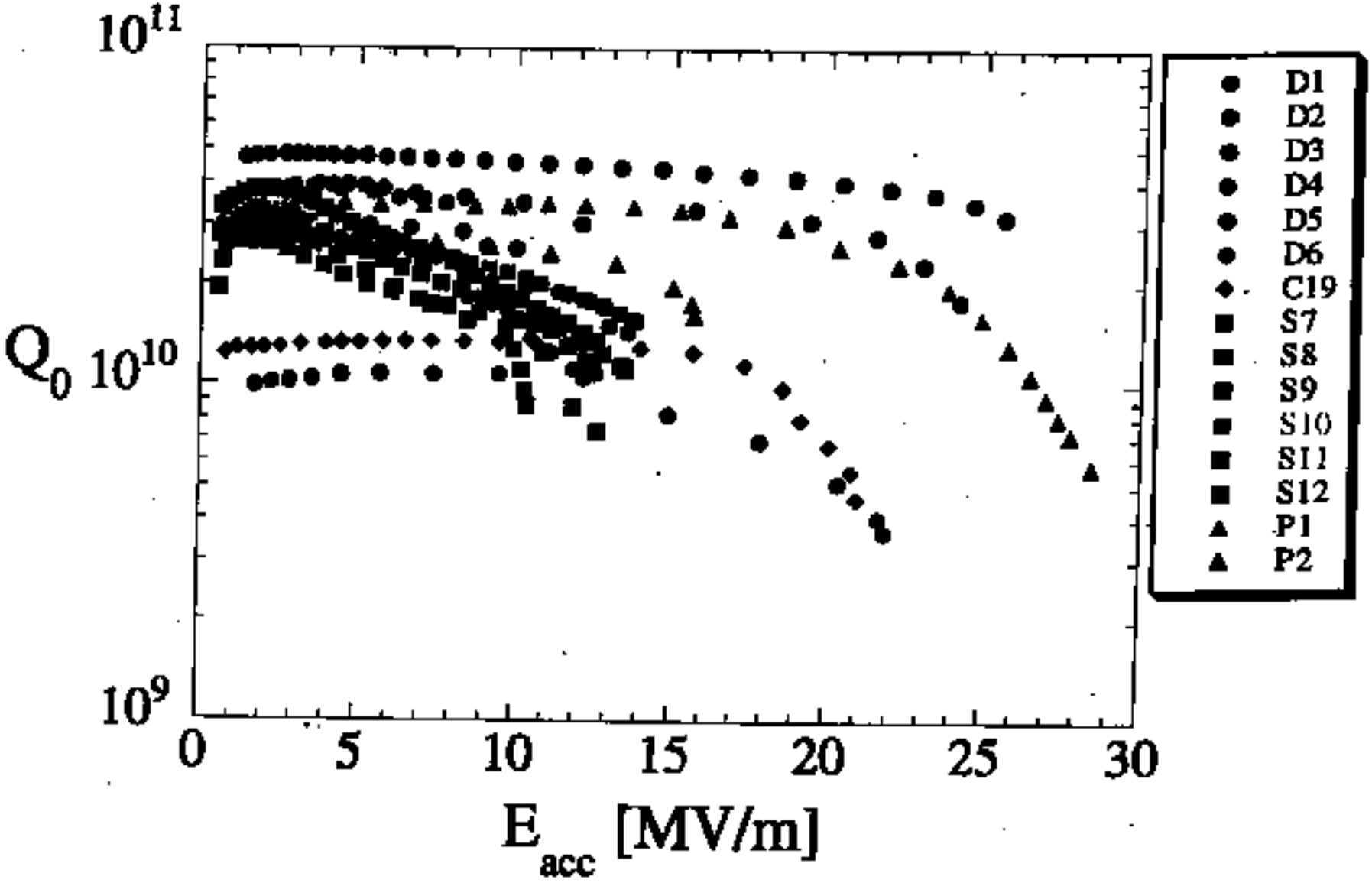
- Build clean rooms and install and commission the required surface treatment and test facilities at DESY. completed 95/96

- Process and test 40 industrially produced 9-cell 1.3 GHz solid Niobium cavities including couplers and tuners. Tested 24 ca Ordere 26 cav cavitie
  5 MV/m → 15 MV/m → 25 MV/m (20.6 MV/m) → ?
- Design, construct and test low cost, low heat leak prototype cryomodules. Specifical we will construct four 12 m long cryomodules and install into each eight 1 m long 9-cell cavities including all the auxilliaries. Same as Alt cryomod availab
  Have installed and tested the first cryomodule
- Accelerate an electron beam through the string of cryomodules and measure the beam properties before and after acceleration.
  Beam has been accelerated through the first module.
- Test an FEL based on the principle of self amplified spontaneous emission by adding a low emittance rf gun, a longitudinal bunch compression system and an undulator to the test facility. 1999 (Spring)

- Construct a SASE FEL user facility with wave lengths (1st harmonic) between 10nm and 3nm.
  2001 – 2003

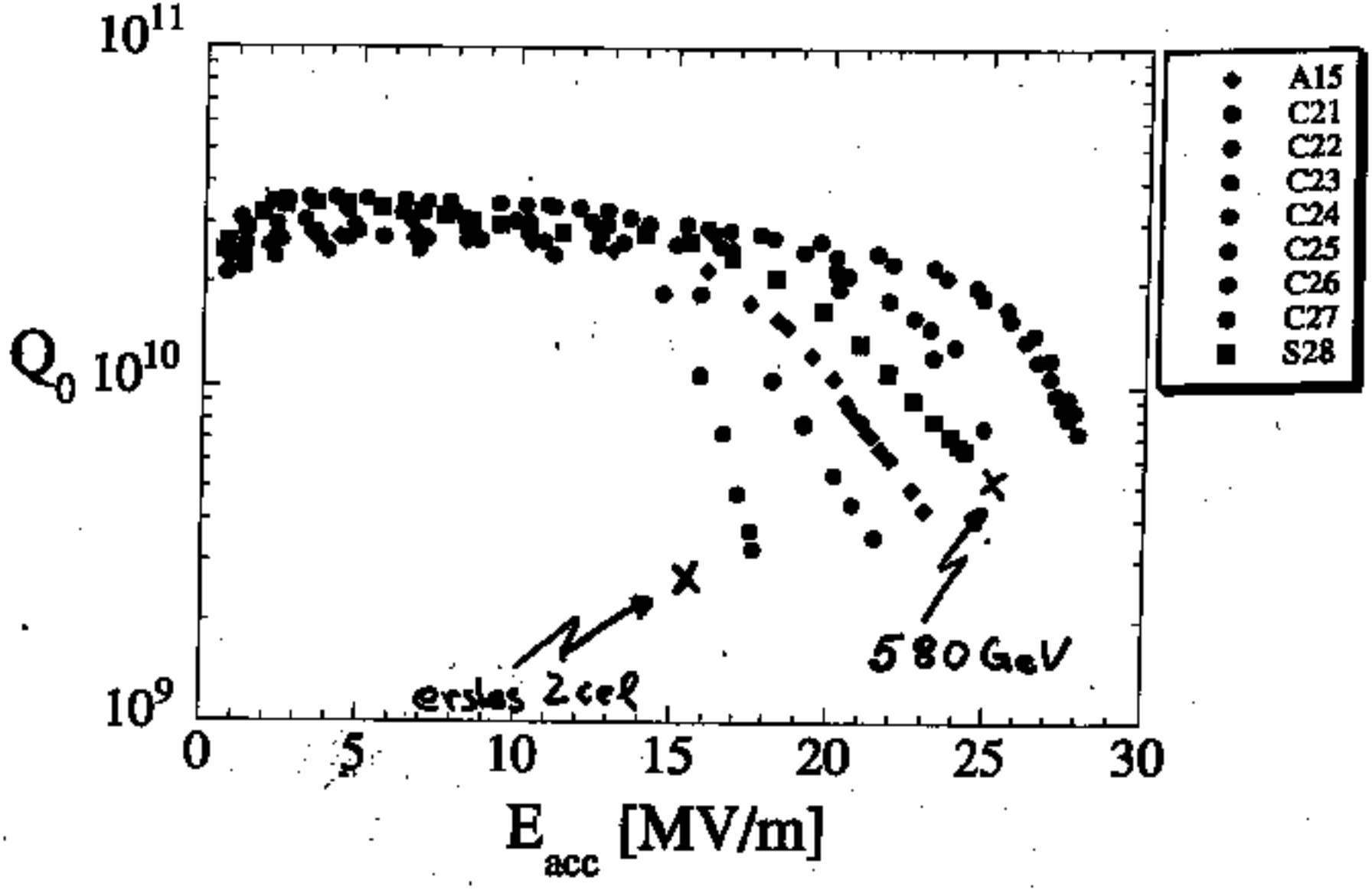

Cavity C21
Cavity was made out of Wah Chang material and fabricated by CERCA
10^{11}
10^{10}
10^{9}
Q_0
x-ray starts
quench
quench
no quench
limited by amplifier
no HT, RRR 400
HT 800 C, RRR 400
HT 1400 C, RRR 770
0
5
10
15
20
25
30
E_{acc} [MV/m]

The 15 first S.C. cavities



average gradient at $Q_0 > 3\ 10^9 = 16.4$ MV/m

The 9 most recent cavities



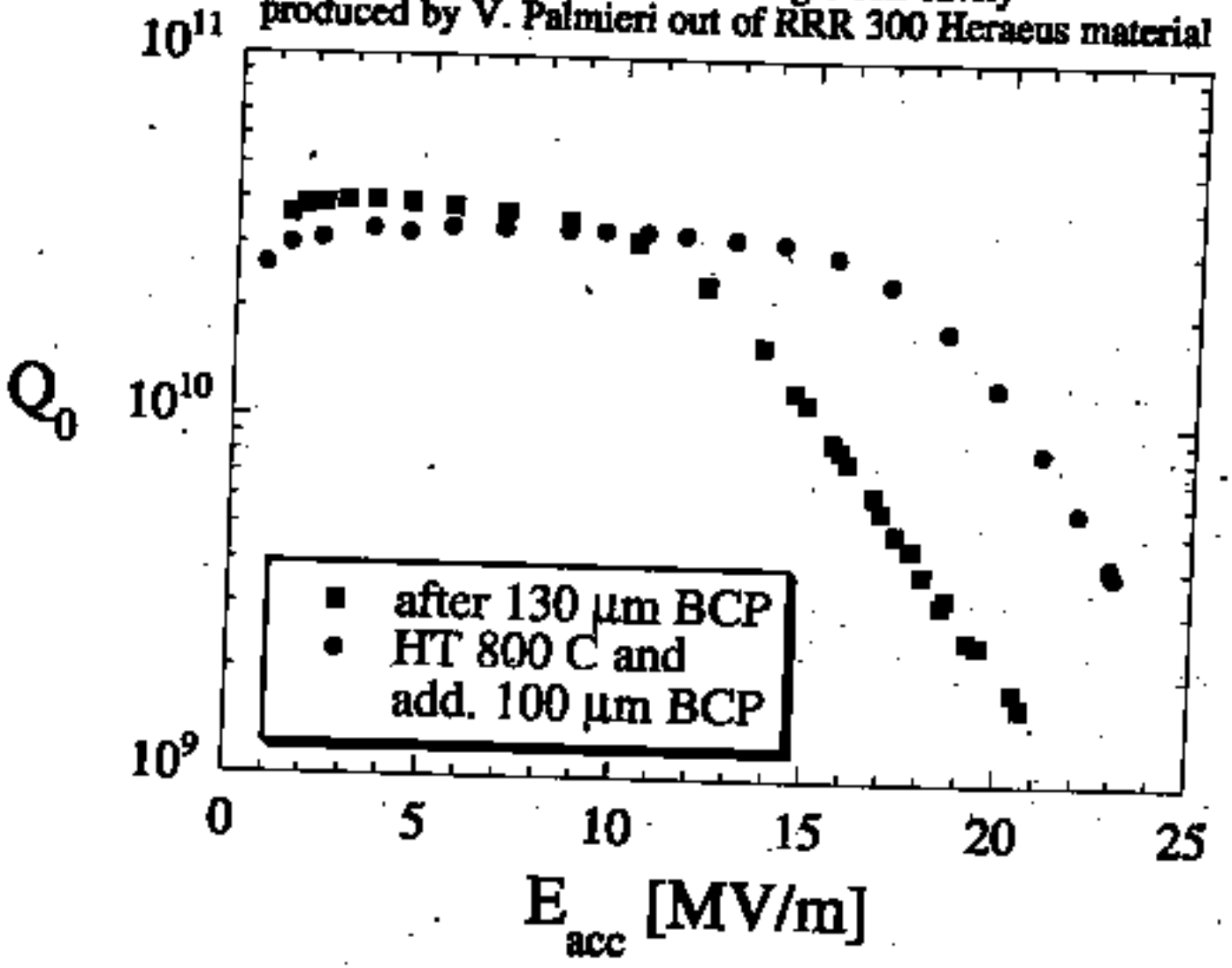
average gradient at $Q_0 > 3\ 10^9 = 23.9$ MV/m

2.1 MV/m is needed to reach 500 GeV

ZENITH

Cavity 1P4

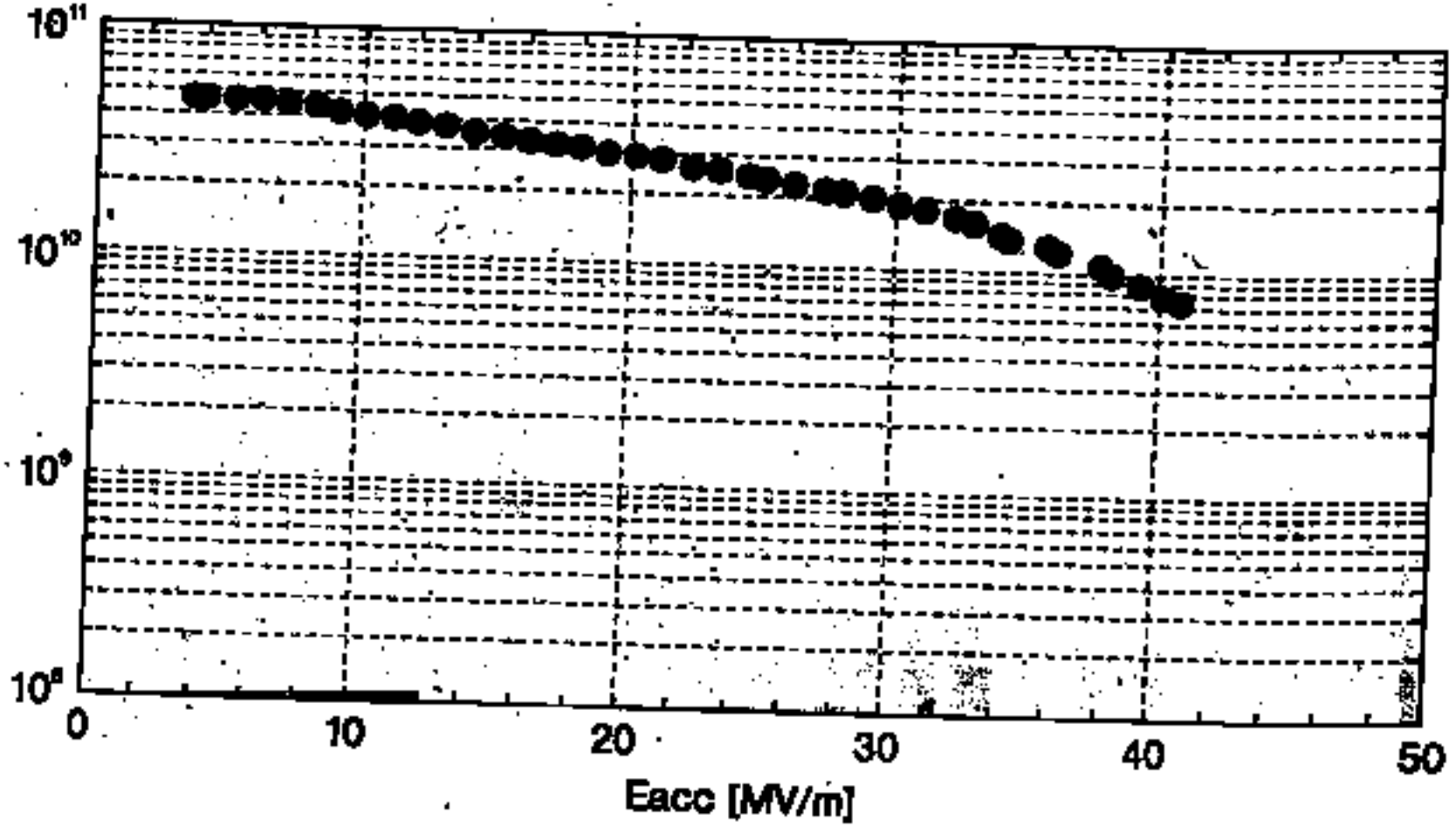
1P4 is a seamless single cell cavity
produced by V. Palmieri out of RRR 300 Heraeus material



Missing Desy

1 cell L-Band K-14 Cavity, 1st Meas., 96 04. 19-24 (Kako etal., KEK)

Annealed half-cells (1400°C), Tumbling (10μm), EP (100μm),
Heat Treatment at 800°C for 5 hours, HPR (p.w.), Shower Rinsing (p.w.)



Status Cavities

- Nb - material as presently available and present production and processing techniques will yield cavities which meets the TESLA goals ($25 MV/m$, $5 \cdot 10^9$

- Strict quality control of Nb sheets and of the production / processing steps are needed to consistently produce TESLA quality cavities.

  ↦ next series of 26 cavities will answear this question

  ↦ finalize production and processing procedures. Industrial Study of welded cavities is underway

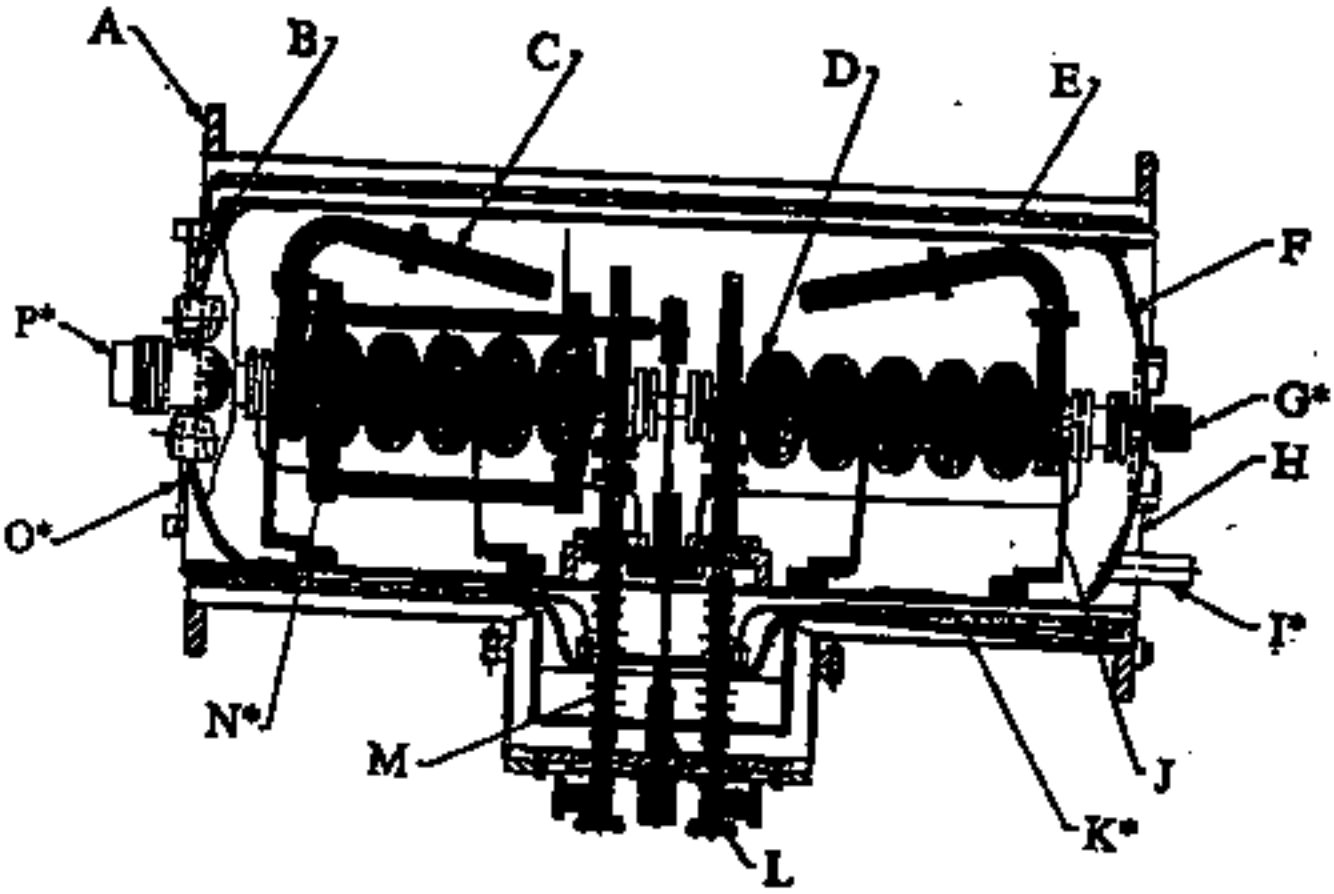
  ↦ Cavities produced by spinning or hydro forming. Cheaper and more reliable.

  ↦ Effort to reach higher gradients
  - better material
  - "new" processing methods (electropolishing)

~1m of cavities.

TOP VIEW OF CRYOUNIT

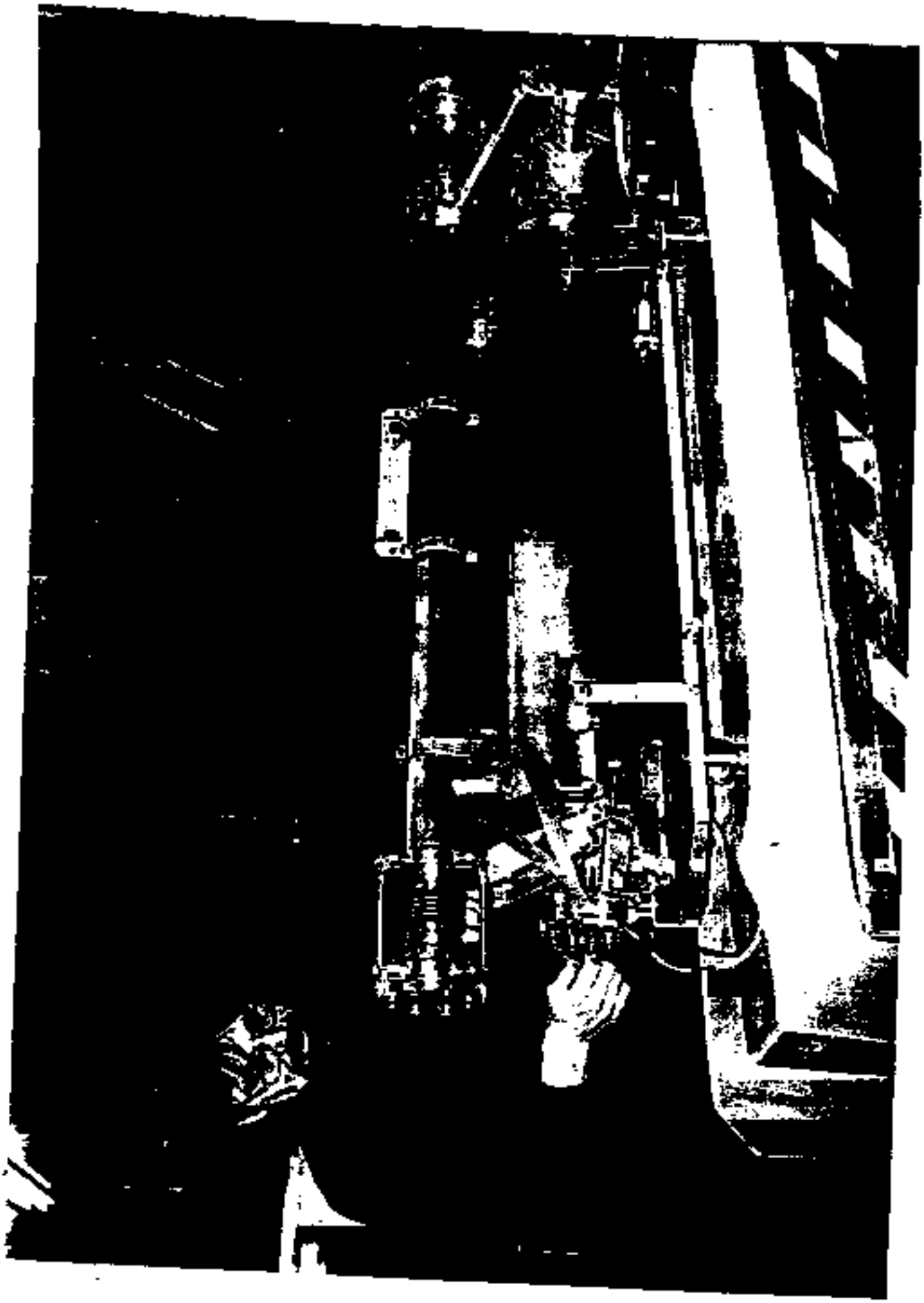
CEBAF

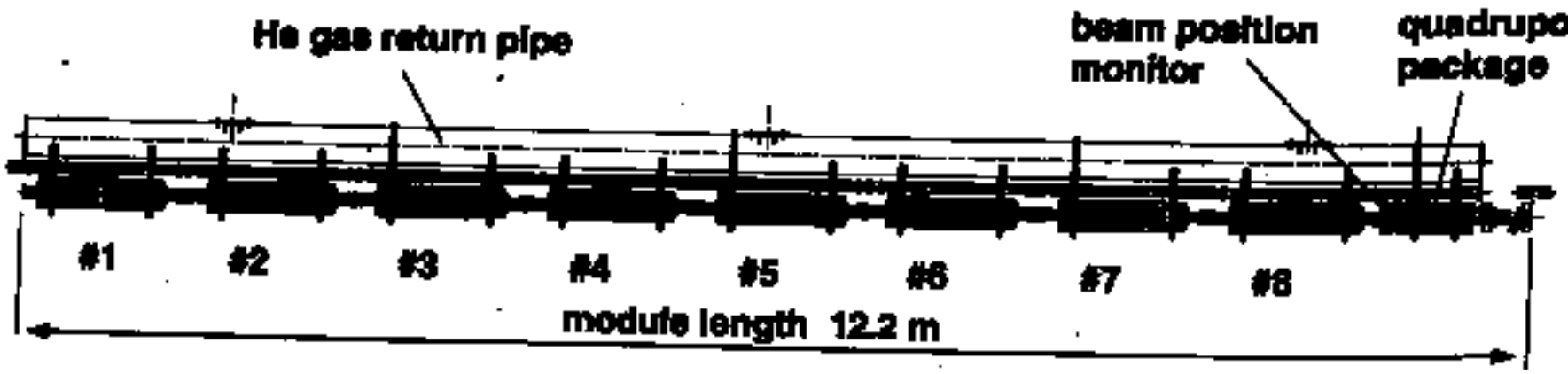


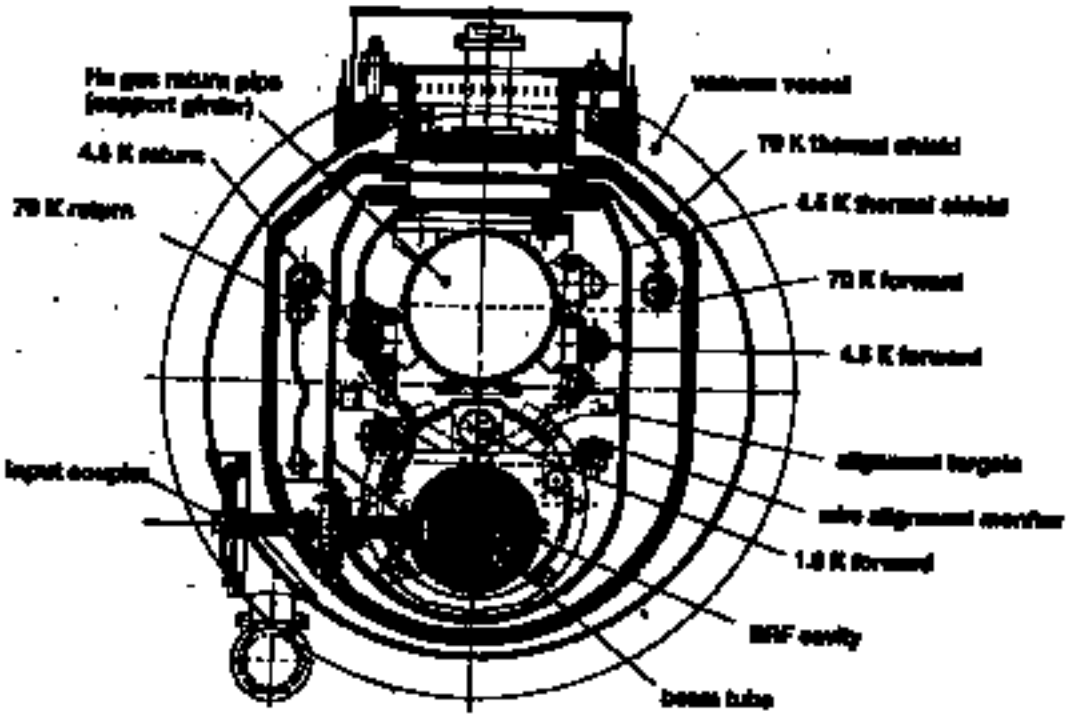
A. Vacuum Shell Flange
B. Magnetic Shield and Inner Superinsulation
C. HOM Load
D. Cavity
E. Shield Superinsulation
F. Helium Vessel
G. Flange Surface on Isolation Valve
H. 40 to 50 K Radiation Shield
I. Shield Helium Supply Line
J. Outboard Cavity Support
K. Axial Support
L. Rotary Feedthrough
M. Fundamental Power Waveguide
N. Tuning Mechanism
O. Helium Vessel Support Rod
P. 2 K Helium Return

*Asterisked items shown only once to simplify illustration.

The most modern layout around

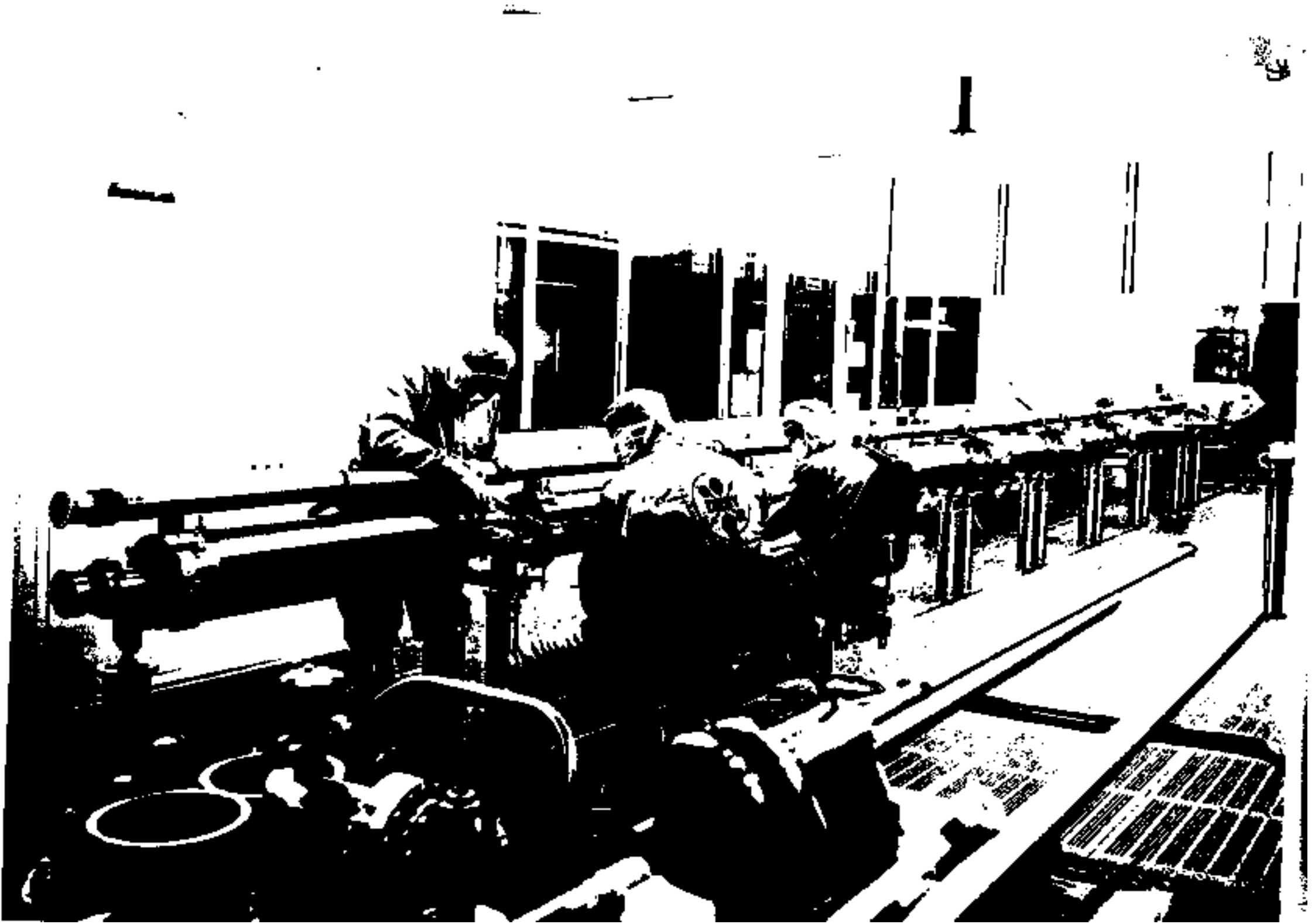


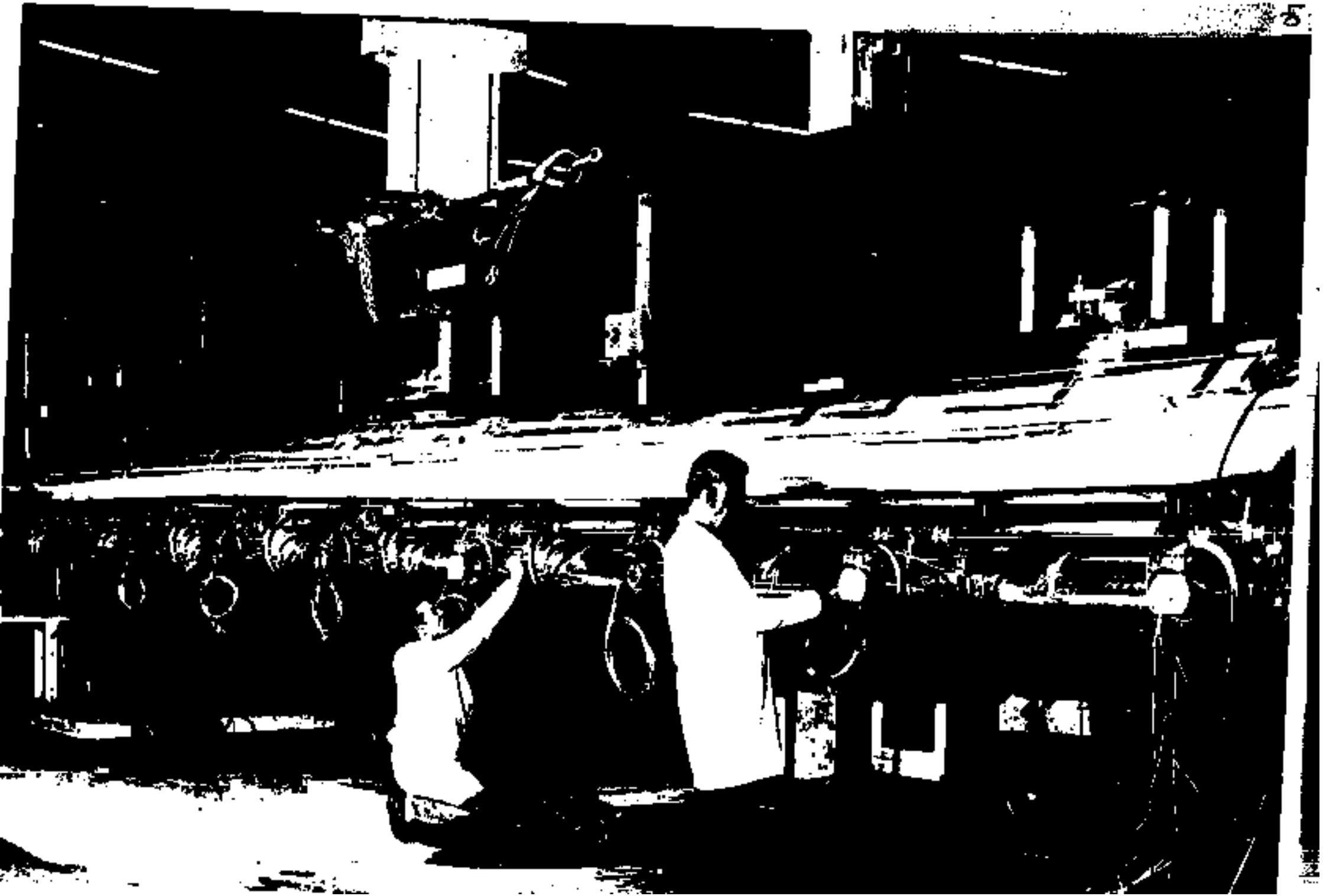


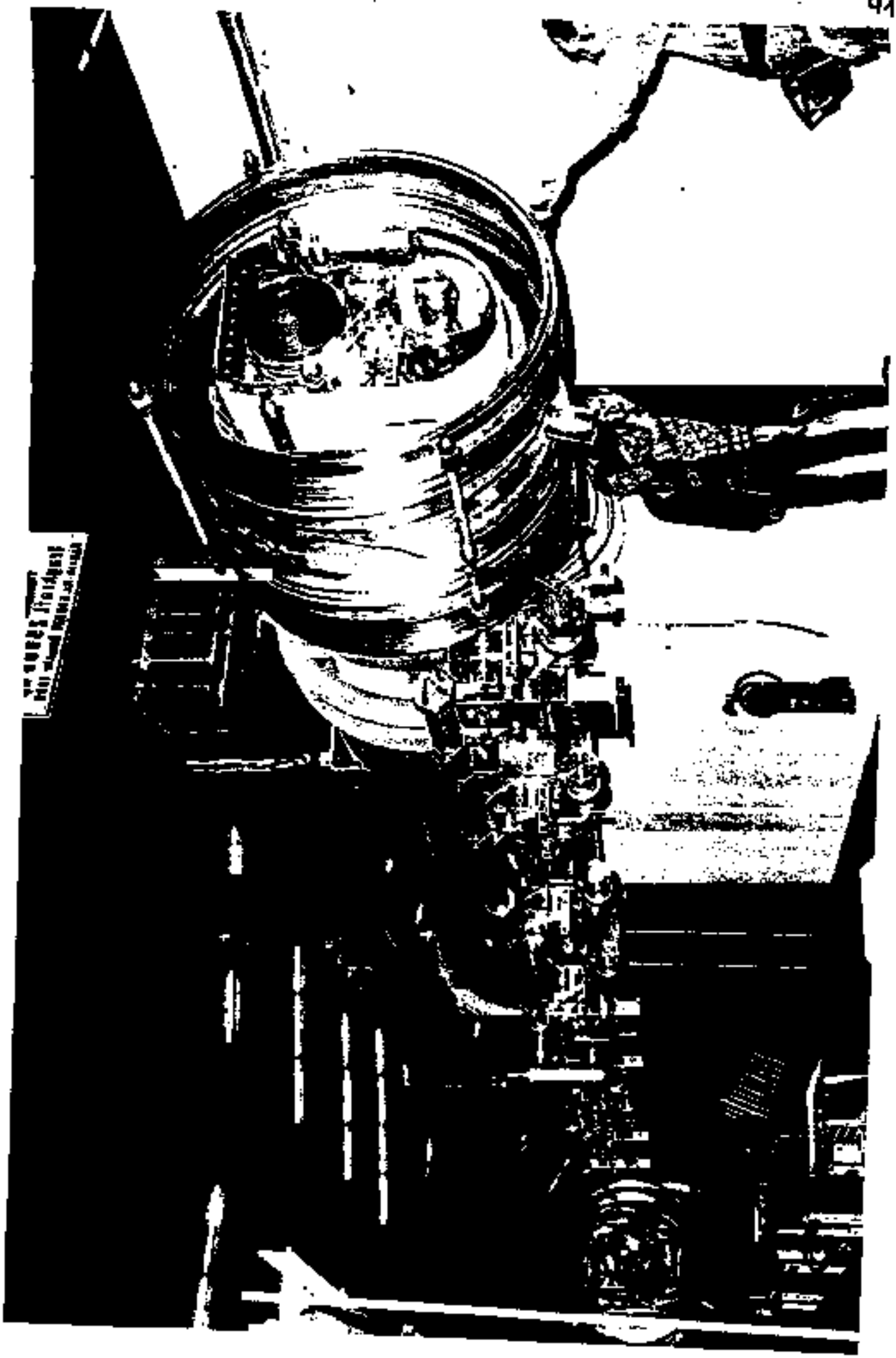


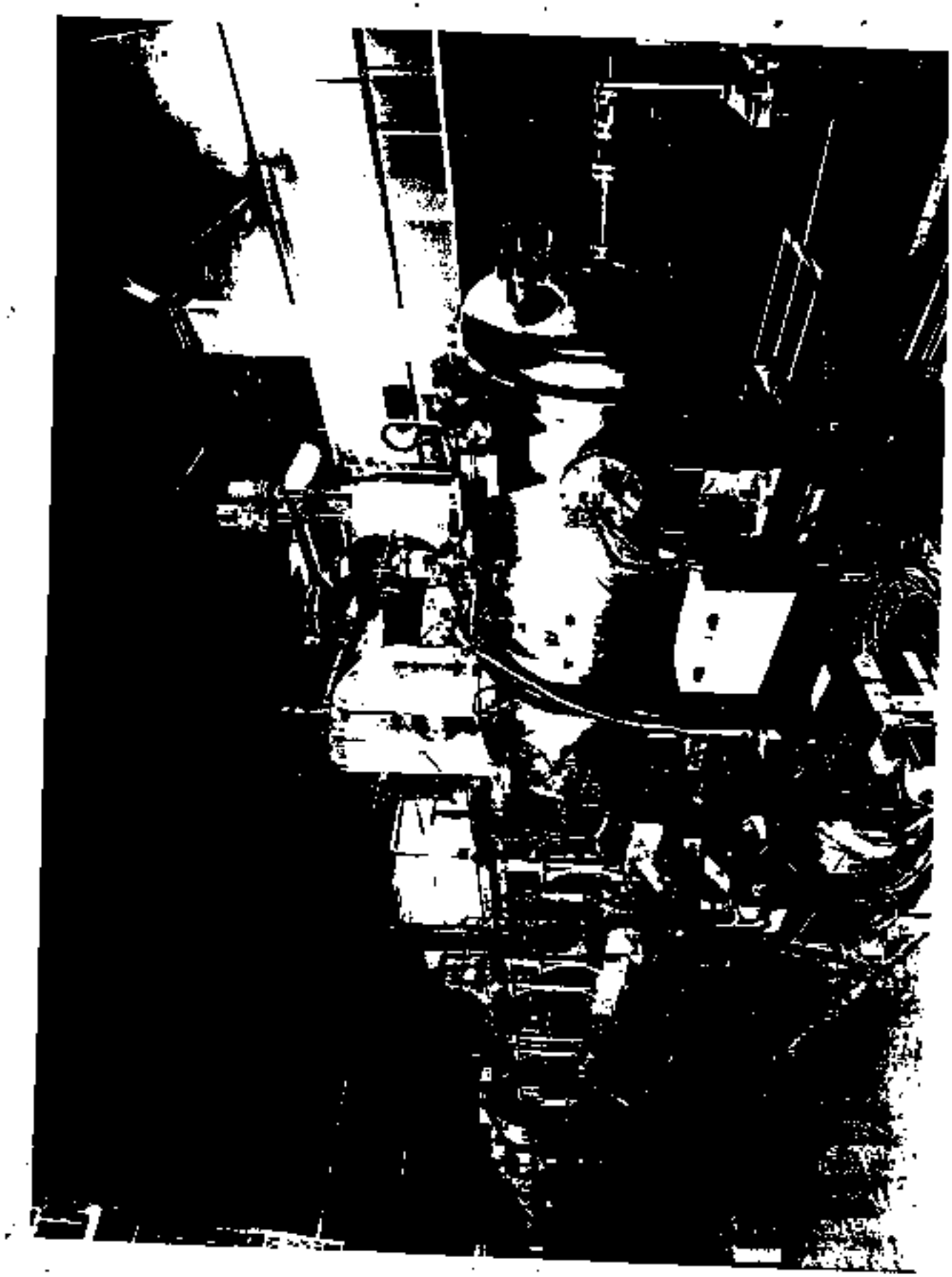
- He gas return pipe (HeGRP) is supported from above by three support posts (fiberglass pipe); it acts as a girder and is used for alignment
- the 8 cavities, the quadrupole package, and auxiliary equipement are attached to the HeGRP by means of stainless steel collars
- two aluminum radiation shields are at intermediate nominal temperature of 4.5 K and 70 K; they are cooled by means of flexible copper braids connected to the centerline of the shield upper section
- the input coupler penetrate both shields and have special radiation shield 'cones'
- approx. 120 temperature sensors and 2 accelerometers are mounted on the prototype module
- the measured static heat load for cryomodule #1 is

6 W @ 1.8 K
23 W @ 4.8 K
80 W @ 70 K

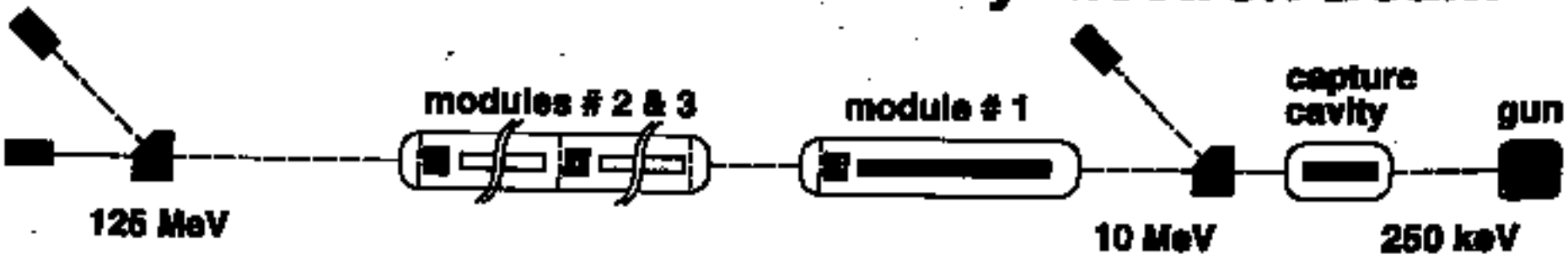




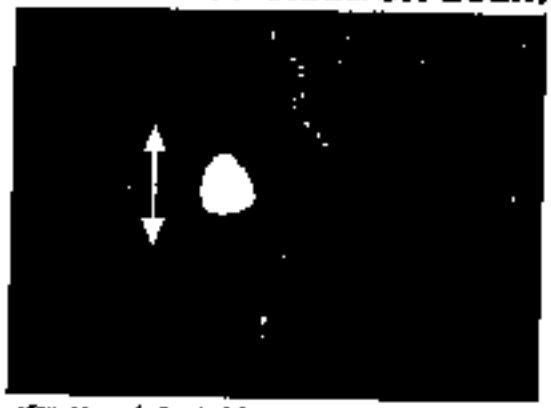




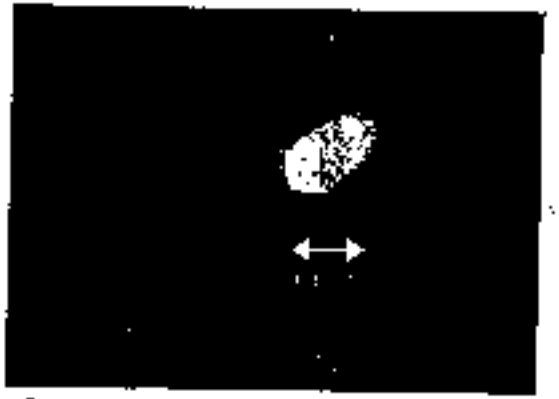
The First TESLA Test Facility Electron Beam



accelerated electron beam

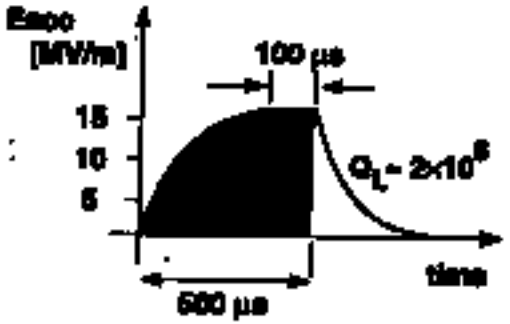


View downstream in front of the 20 deg spectrometer magnet



View upstream in front of the beam dump

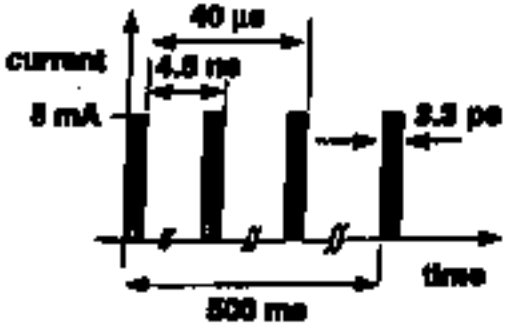
accelerating module



accelerating module	
acc. gradient	16.7 MV/m
energy gain / cavity	16.5 MeV
beam energy	125 MeV

- 7 cavities are in operation
- quench limit at 16-19 MV/m (depending on rf macro pulse length)
- the present schedule:
  - increase rf pulse length and macro pulse repetition rate
  - measurement of cryogenic load

injected electron beam

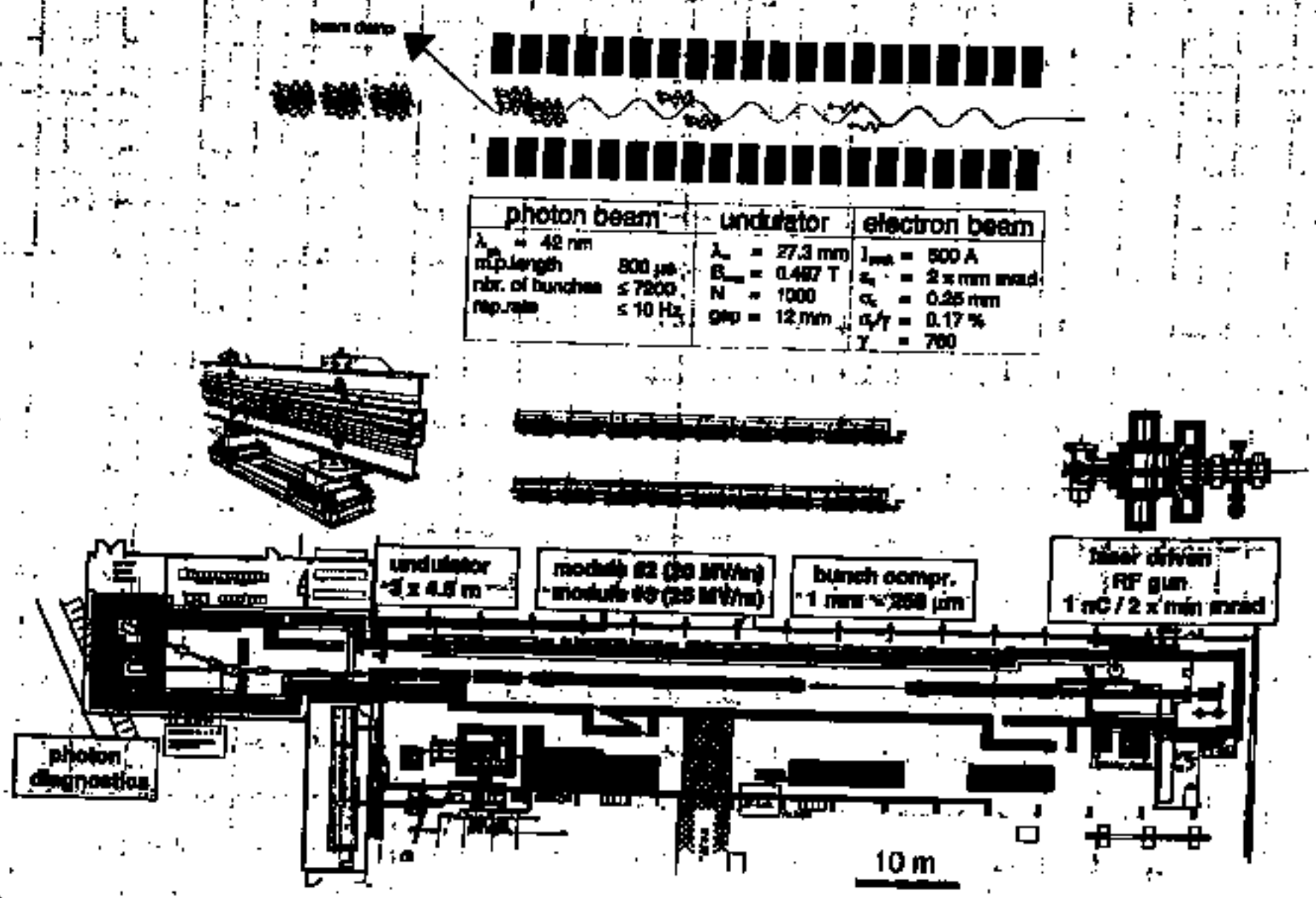


electron gun	
beam energy	250 keV
beam current	5 mA
macro pulse length	40 µs
repetition rate	2 Hz
capture cavity	
accelerating gradient	11 MV/m
beam energy	9.8 MeV
rf pulse length	1.3 ms

Integrated System Test

- There is a ~10% reduction in gradient between the initial measurem of a "naked cavity" in the vertical tes cryostat and the gradient observed with beam
- The module (7 cavities) was operated reliably and reproducibly over seven months.
- The cavities were extremely insensitive to vibrations in the hall
- The measured heat load at 1.8K is less than 1 Watt / m.
- A single klystron can be used to drive a large number of cavities without deleterious effects

SASE Proof of Principle Experiment



TTF-II

- By extending the tunnel an additional 5 + 2 modules may be added raising the energy to 1 GeV or beyond.

- Dual use:

  Driver of an SASE-FEL for Λ between 2 nm and 30 nm

  TESLA Prototype

- New features:
  - new cryostat
  - in part seamless cavities
  - high filling factor
  - final tuner / HOM / Couplers
  - multibeam klystron
  - new type of modulator

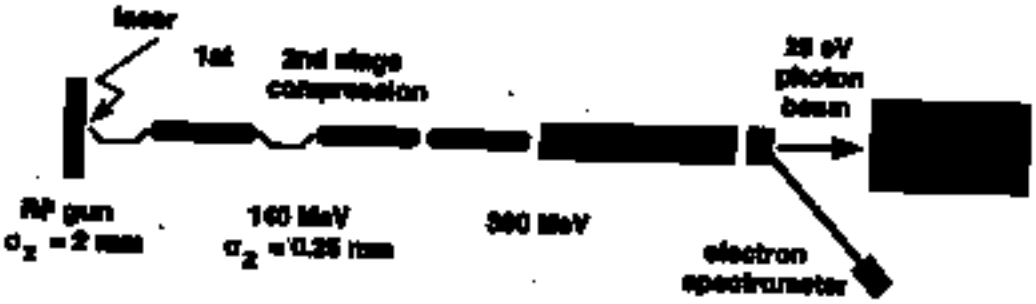
  and much more

Start of construction: 1998

Start of commissioning: 2001/2002

Program 1998 - 2003

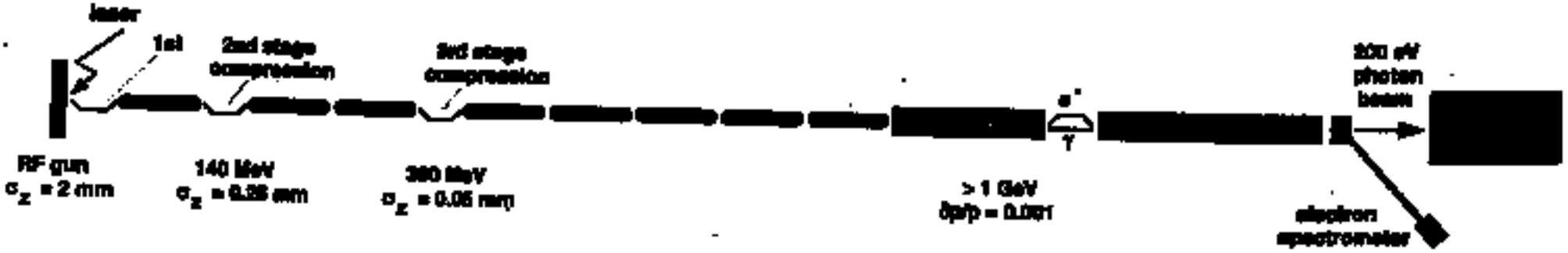
TTF with SASE FEL Proof of Principle Experiment



Linac 400 MeV end of 1998
Module #2 E_{acc} ~ 20 MV / m
Module #3 E_{acc} ~ 25 MV / m

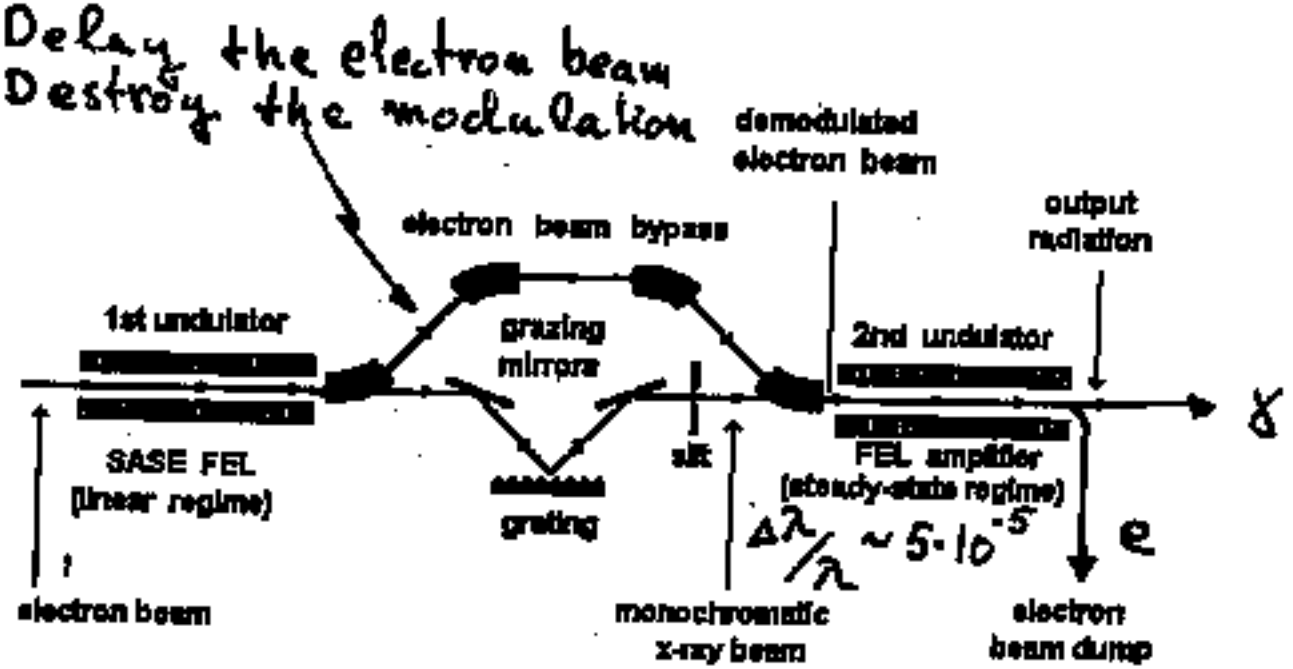
SASE FEL Test at λ ~ 40 nm
Undulator ready for installation
by the end of 98; test spring 99

TTF II with SASE FEL User Facility



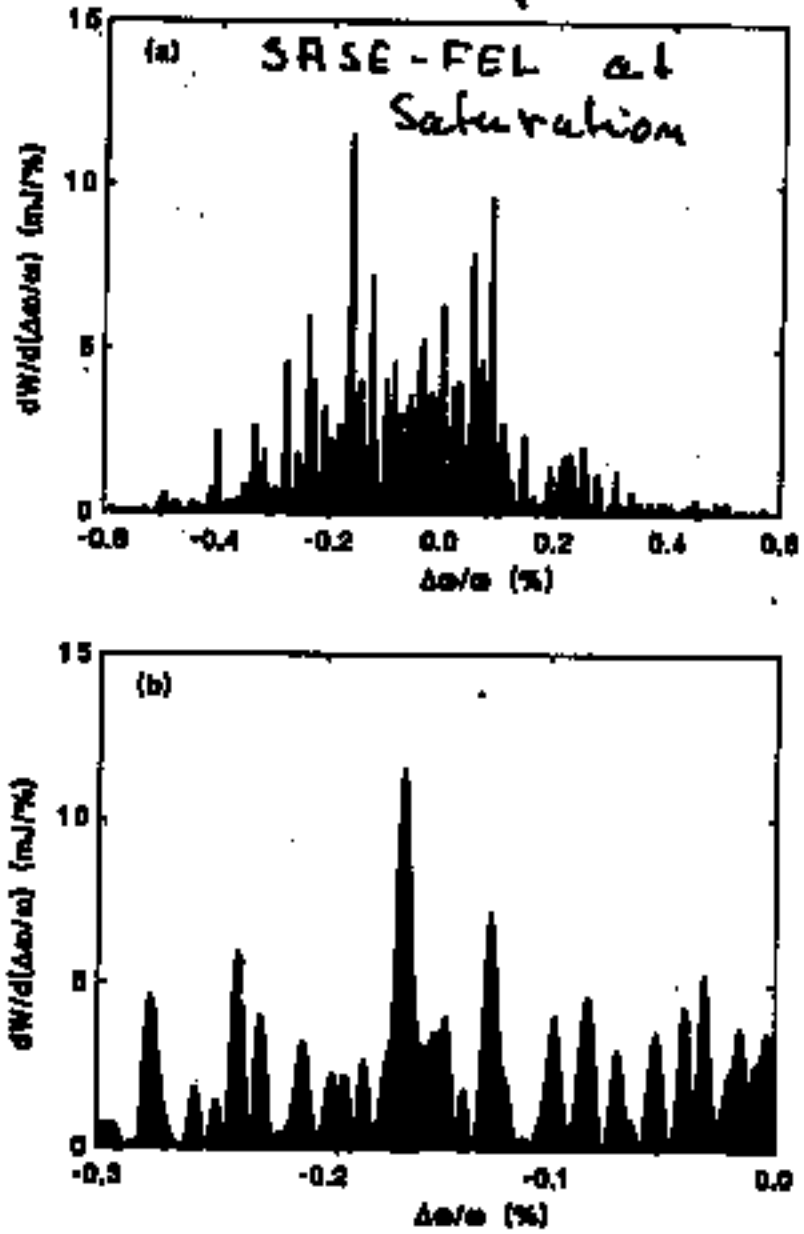
J. Feldhaus, E.L. Saldin, J.R. Schneider, E.A. Schneidmiller, M.V. Yurkov

Possible application of X-ray optical elements for reducing the spectral bandwidth of an X-ray SASE FEL



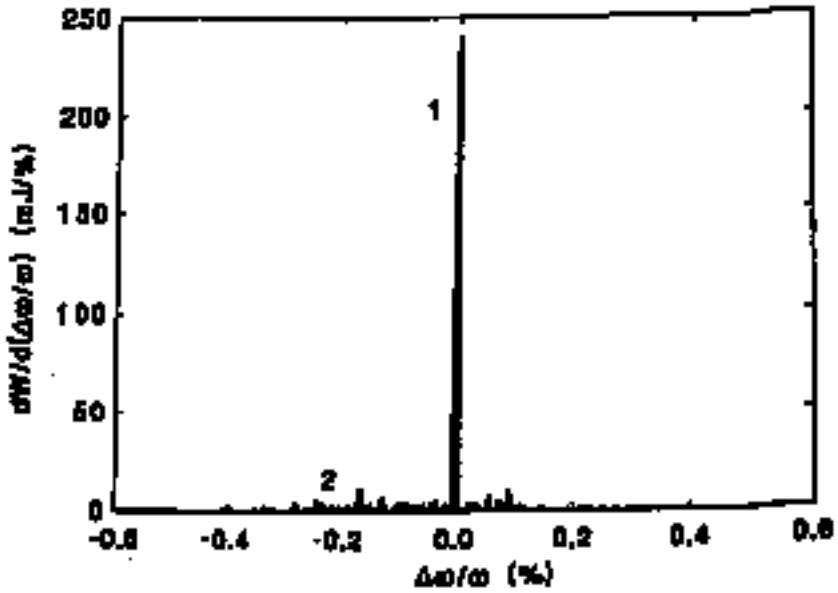
The principal scheme of a single-pass two-stage SASE X-ray FEL with monochromator.

Power Spectrum of a conventional

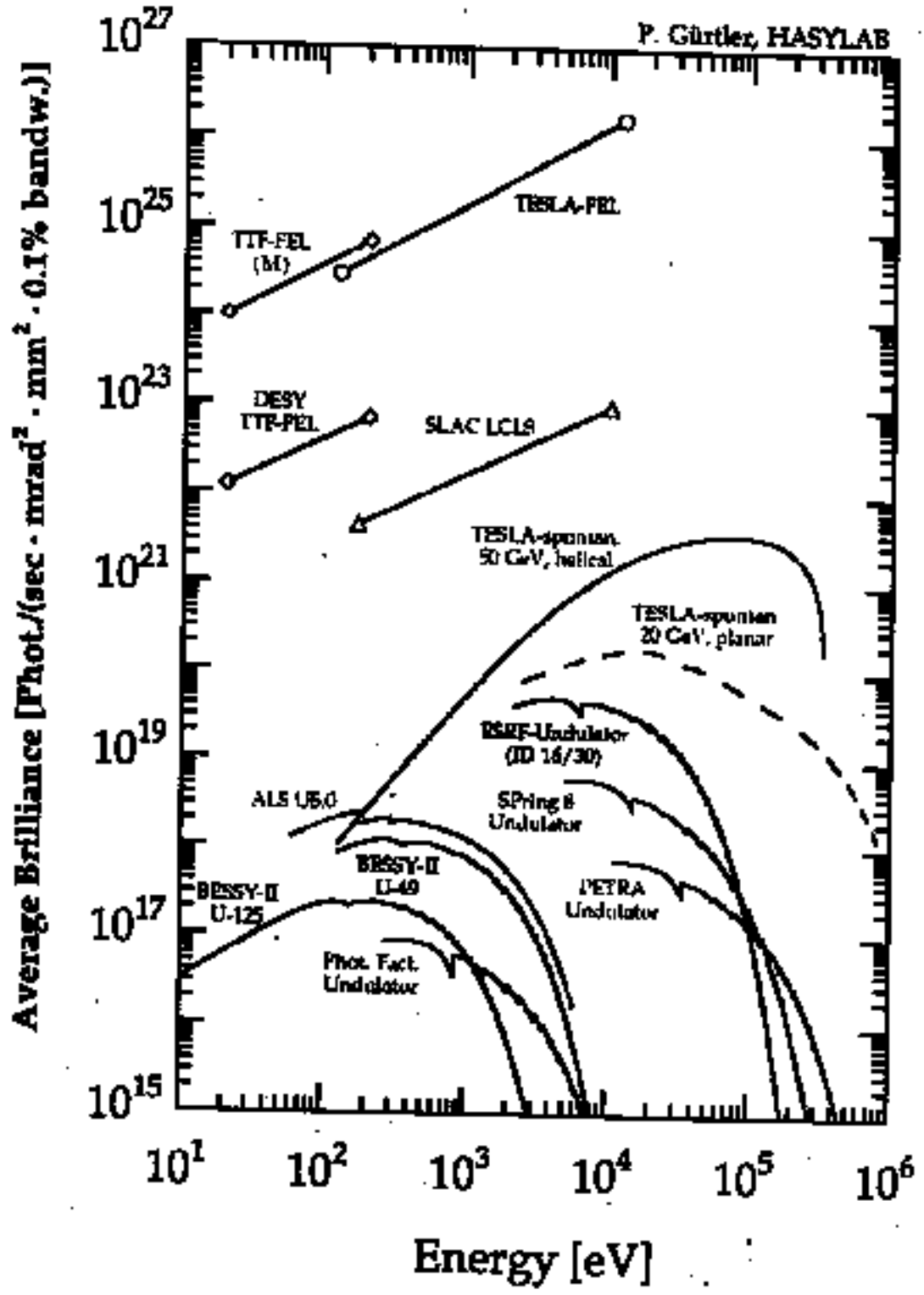


Spectral distribution of the radiation pulse at the saturation point of the conventional SASE FEL. Graph (a) is a plot of the full spectrum and graph (b) presents an enlarged fraction of graph (a).

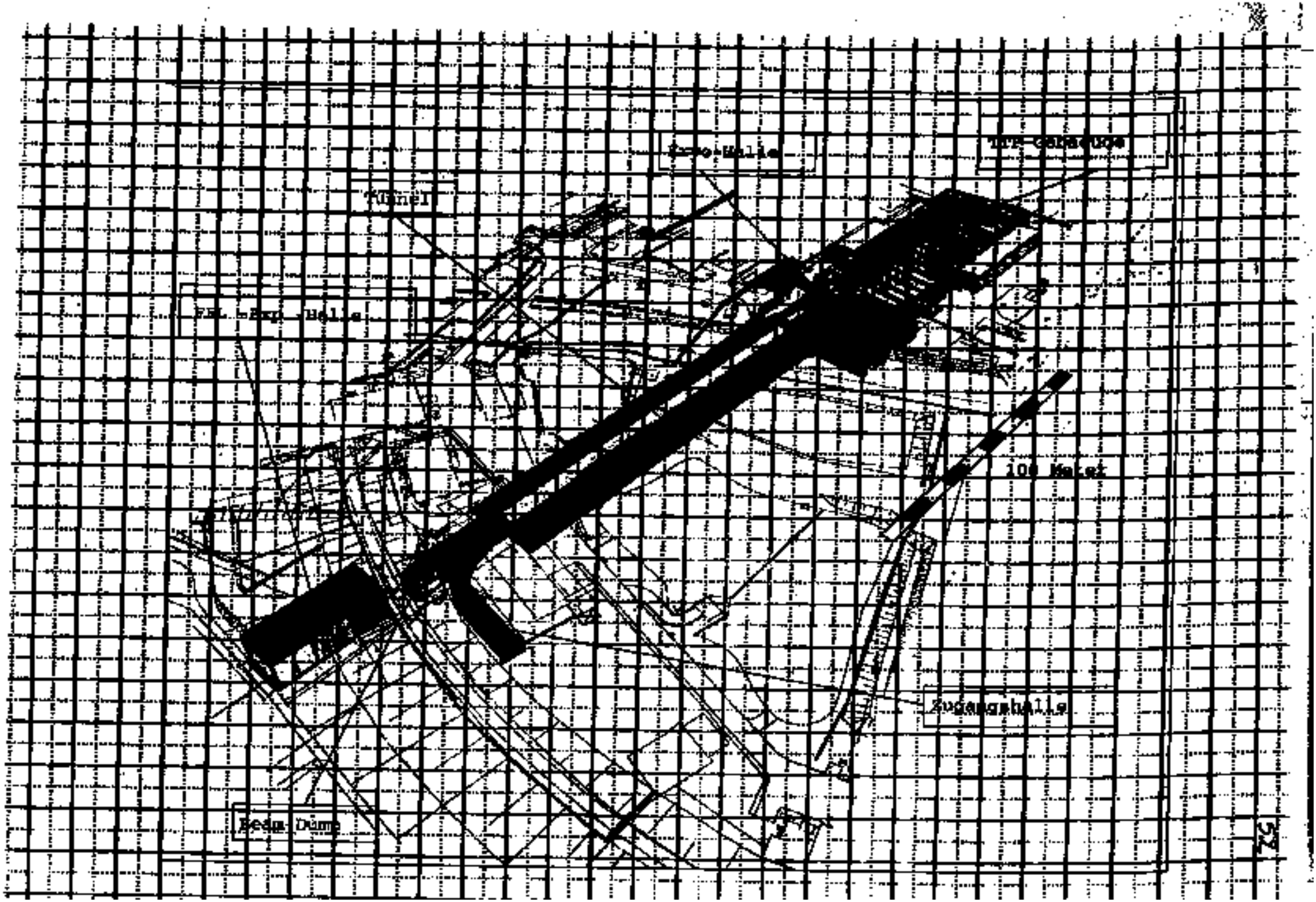
Power Spectrum of an FEL amplifier operating in the steady state regime. P_{in} = 10kW



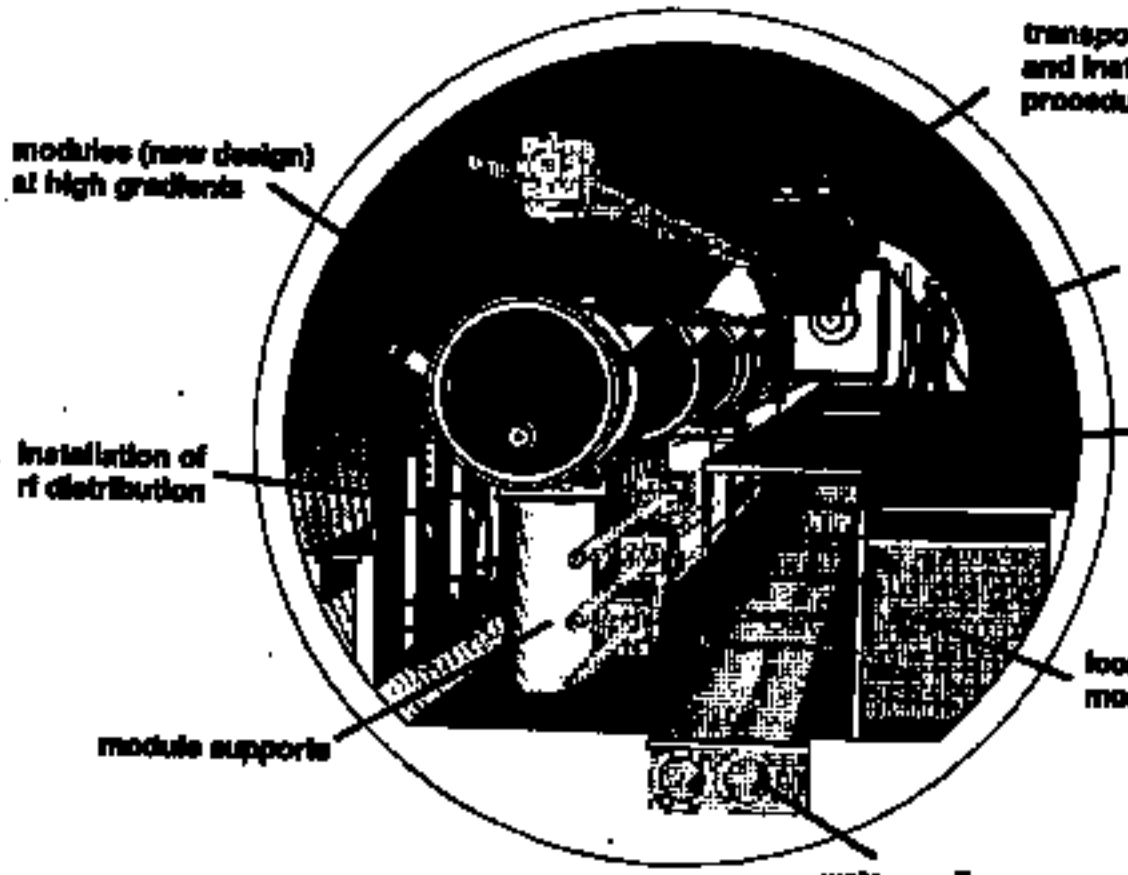
Spectral distribution (1) of the energy in one radiatio pulse of the FEL amplifier operating in the steady-state regime fc an input power P_{in} = 10 kW and an undulator length L_w = 16 : (saturation point). Curve (2) presents the typical spectrum of conventional SASE FEL operating at saturation.



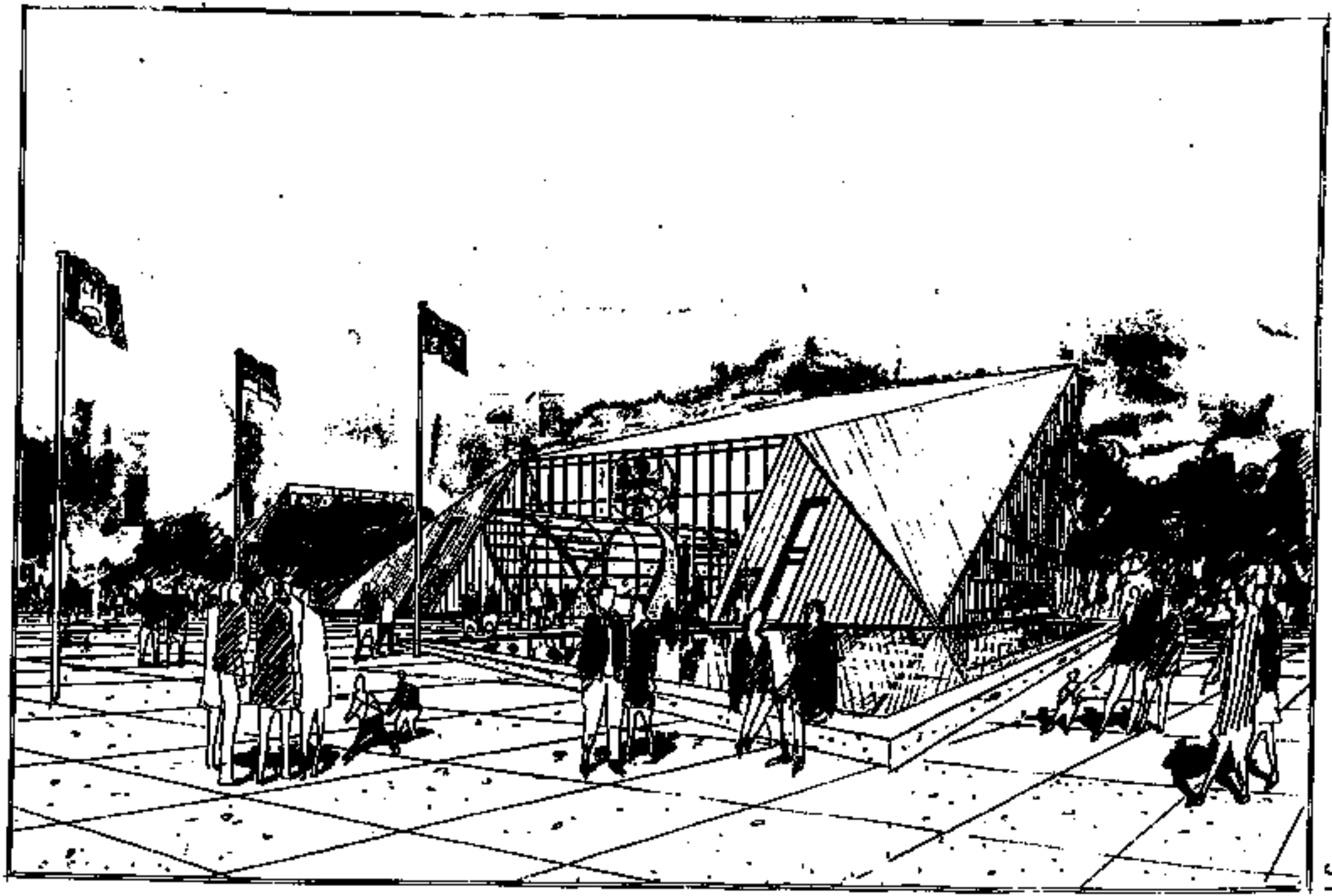
Spectral average brilliance (1.4%)


Tunnel
100 Meter
Zugangshalle
Beam Dump

TTF Linac Extension as TESLA 500 Test Area



not shown: the construction cost of a tunnel like building covered with sand is less than the setup of a long shielded area; a rectangular cross section is also more expensive



The TESLA Road Map

1997
- Conceptual Design Report completed.
- CDR reviewed by the DESY Extended Scientific Council
- Intergovernmental (Hamburg-Schleswig / Holstein) working group on the public planning process for the construction of TESLA constituted
- First operation of the TESLA Test Facility at ~120 MeV.
- SBLC will be terminated in 1998

1998
- Construction of TTF II started
- Intergovernmental Agreement on the Public Planning Process for TESLA signed by the two Ministers responsible
- Environmental impact Study authorized. ("Scoping Process")
- Joint ECFA-DESY working group on the physics potential of the TESLA high Luminosity Option
- Industrial Study of main Components

- Presentation of the Project to the public.
- Operation of TTFI at ~400 MeV

1999
- Test of the SASE-FEL at λ=40nm
- Sitges Meeting: Comparison of the physics / detector analysis obtained by the ECFA/DESY group with the results of the joint KEK/SLAC study
- Decision on the proposed evaluation of the TESLA project by the German Science Council
- Presentation of the Project to Members of the Parliaments and to Industry

2000
- Expo 2000 "SASE-FEL" at DESY
- Design Report including Cost and Schedule
- Comparison with KEK/SLAC design
- International Project Organisation

2001. • Evaluation of the Project and comparison with other large Science Projects in Germany

• Start Commissioning of TTF II including VUV-Laser.

• Proceed with the Public Planning Process

2002/2003 **Decision.**

Construction Time

6 to 7 years.