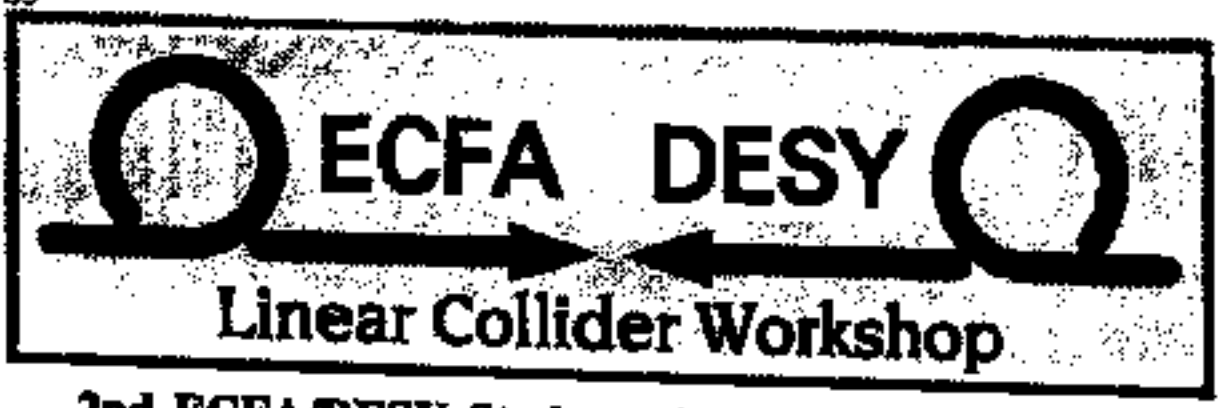
S3




**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 - 14:40

**Speaker** : R. Brinkmann

Progress with TESLA, including where the high luminosity comes from and successful tests on cavities.

# Progress on TESLA Design for High Luminosity

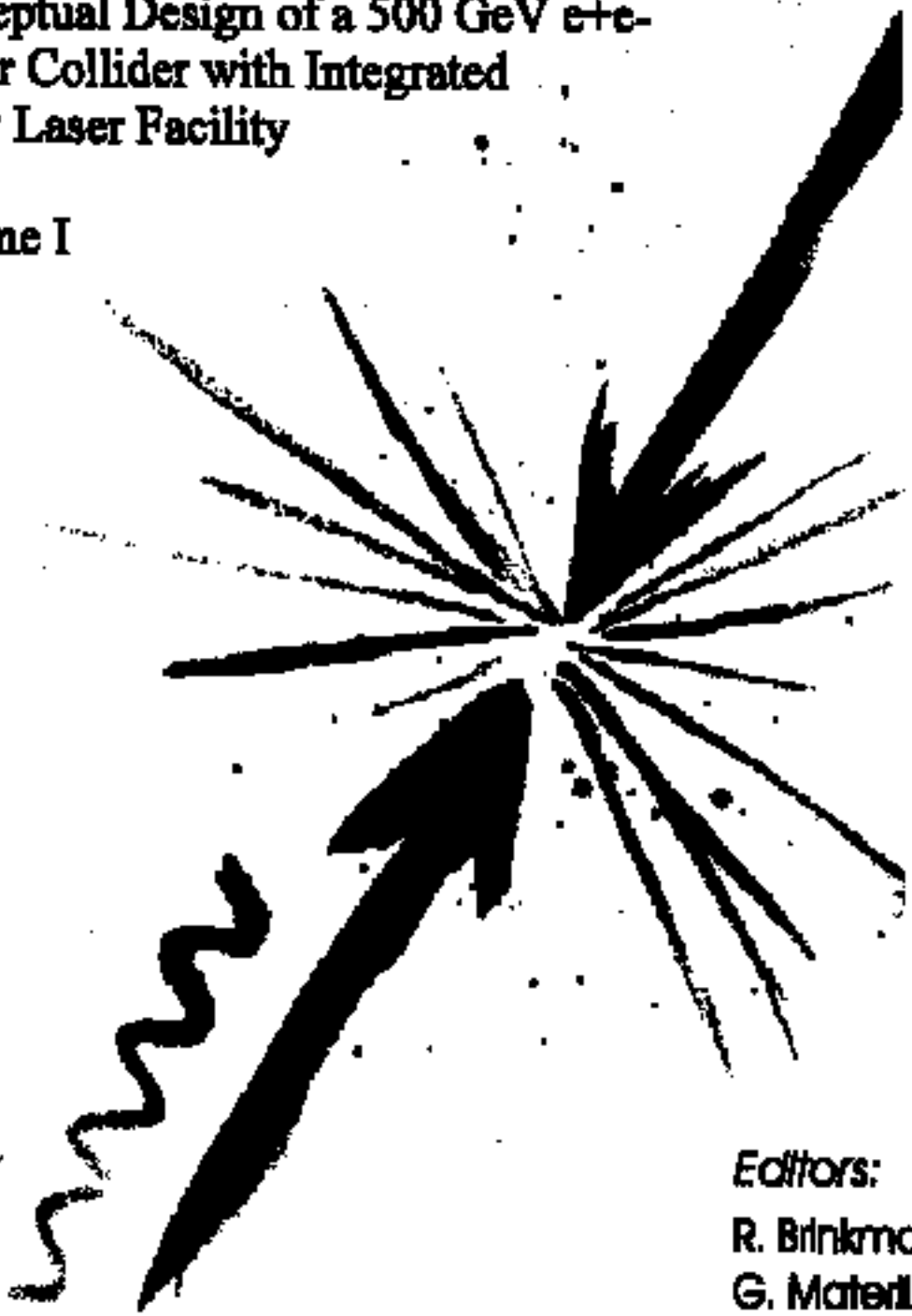
R. Brinkmann, DESY

DESY/ECFA workshop Orsay, April 1998

- Summary of TESLA reference design
- Design optimisation
- Impact on the collider sub-systems
- Site layout

# 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

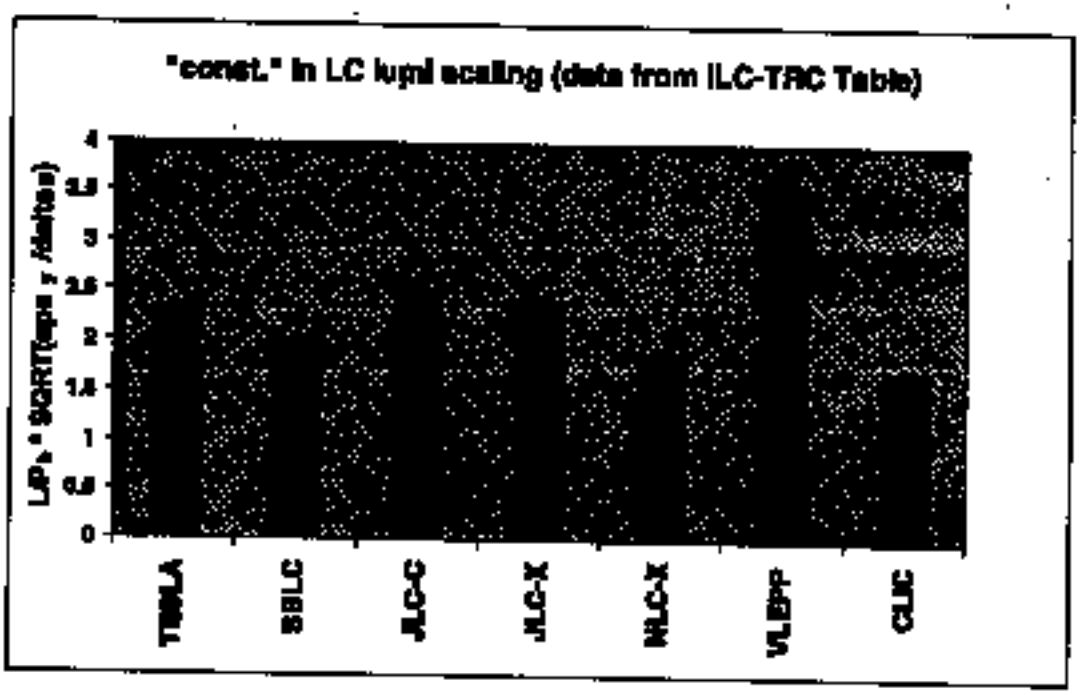
DESY 1997-048
ECFA 1997-182

General LC luminosity scaling:

$$L \propto const. \times \frac{\eta \cdot P_{AC}}{E_{cm}} \cdot \sqrt{\frac{\delta_B}{\varepsilon_y}}$$

⇒ optimised design should have

- **maximum AC-to-beam efficiency** $\eta$
- **minimum dilution of emittance** $\varepsilon_y$



| | TESLA | SBLC | X-band | CLIC |
|---|---|---|---|---|
| gradient [MV/m] | 25 | 17 | 32...55 | 100 |
| AC power [MW] | 95 | 140 | 87...115 | 94 |
| $\eta_{AC\text{-}to\text{-}beam}$ [%] | 17.3 | 10.4 | 6...10 | 10.4 |
| IP $\sigma_y$ [nm] | 19 | 15 | 4...6 | 5.4 |
| luminosity [$10^{33}$] | 6.8 | 5 | 5...8 | 5 |

**high η of TESLA was used to relax spot size demand**

⇒ very relaxed tolerances / high beam stability

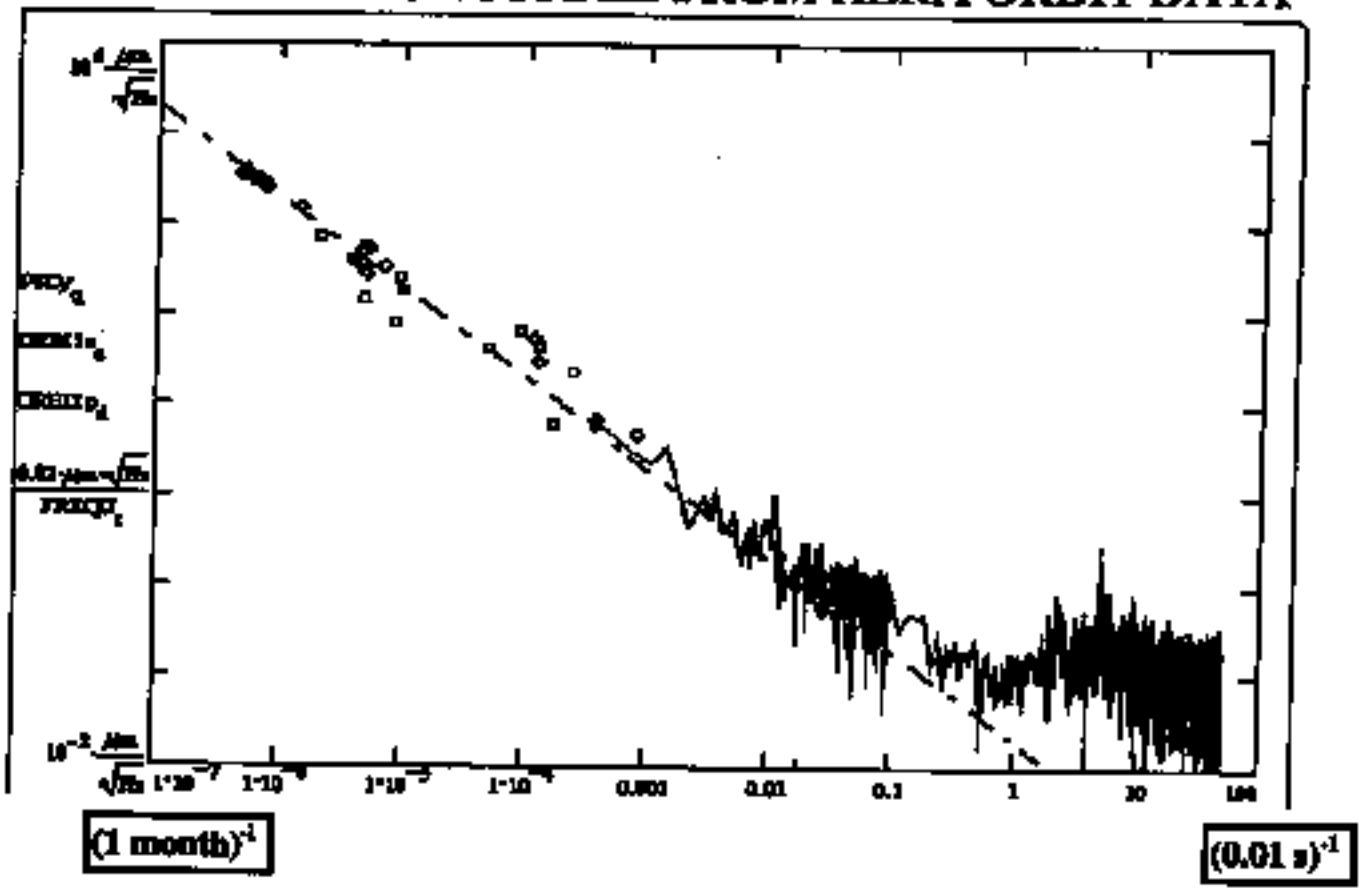
**examples:**

- Main Linac structure alignment and quad position drift tolerances for ~10% emittance dilution

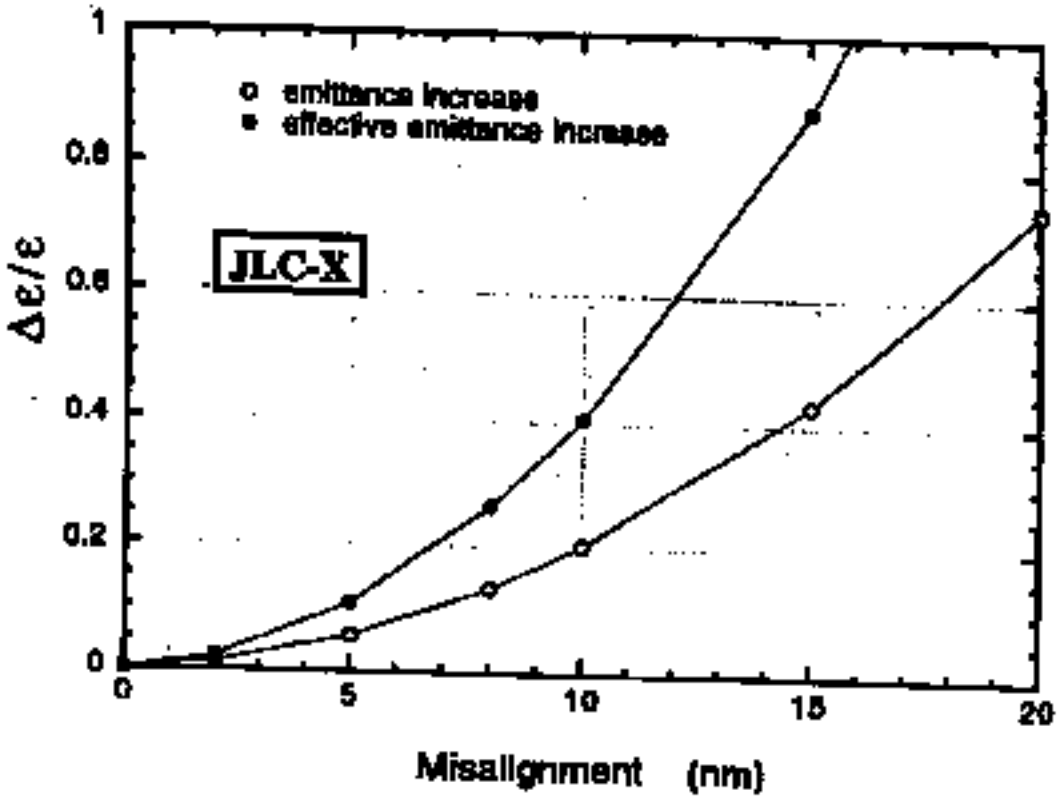
- Spot size growth from position errors in beam delivery system

**using *conservative* assumptions on ground motion (ATL-like) from HERA closed orbit motion data**

# GROUND MOTION MODEL FROM HERA ORBIT DATA




diffusive ground motion: $\delta y^2 \approx A \cdot T \cdot L$ $\quad A = 4 \cdot 10^{-6}\ \mu m^2/m/s$




(for comparison: JLC design study, April 1997, page 217)

| | TESLA | SBLC | X-band |
|---|---|---|---|
| structure alignment [μm] | 500 | 50 | 5...10 |
| BPM-to-quad [μm] | 100 | 5 | 2 |
| quad pos. drift (no corr.) [μm] | 2 | 0.3 | ~0.005 |
| time between orbit correction (ATL-model) | few h | 10 min | ~0.3 s |

Vertical spot size dilution at IP from spurious vertical dispersion in the Final Focus system:

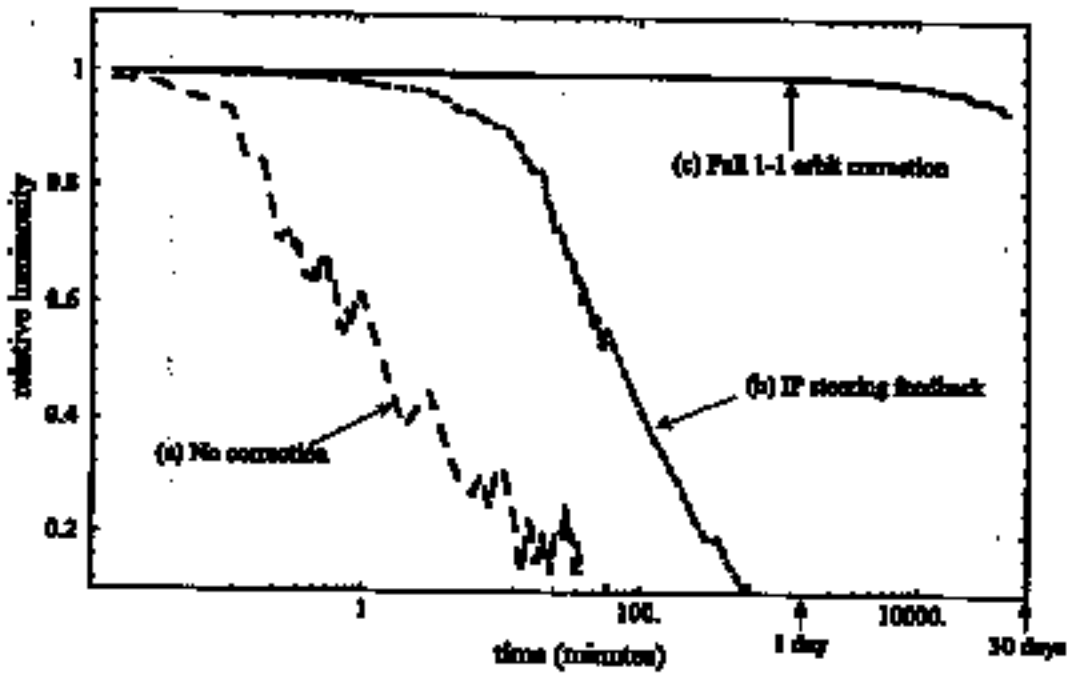
$$\frac{\Delta\sigma_y}{\sigma_y} \approx \frac{1}{2}\cdot\frac{\sigma_E^2 D_y^2(IP)}{\sigma_y^2} = \left(\frac{\sigma_E}{\sigma_y}\right)^2 \cdot \delta_y^2 \cdot F_{optics}$$

"figure of merit" — tolerances

| | TESLA | SBLC | X-band |
|---|---|---|---|
| energy spread $\sigma_E$ [%] | 0.06 | 0.3 | 0.3 |
| spot size $\sigma_y$ [nm] | 19 | 15 | 4...6 |
| f.o.m. [a.u.] | 1 | 40 | ~400 |

- position tolerances scale as 1/sqrt(f.o.m.)
- time between orbit corrections scales as 1/f.o.m.

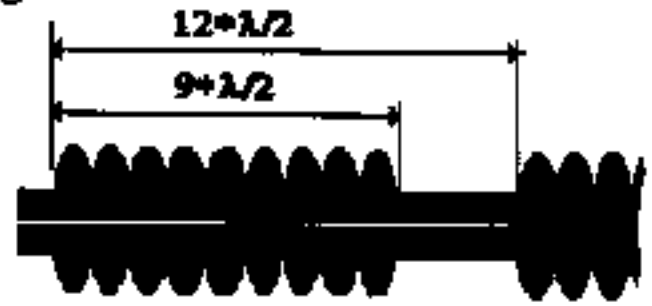
Luminosity reduction from orbit drift (ATL-model) in beam delivery system (MERLIN-simulation, N. Walker)



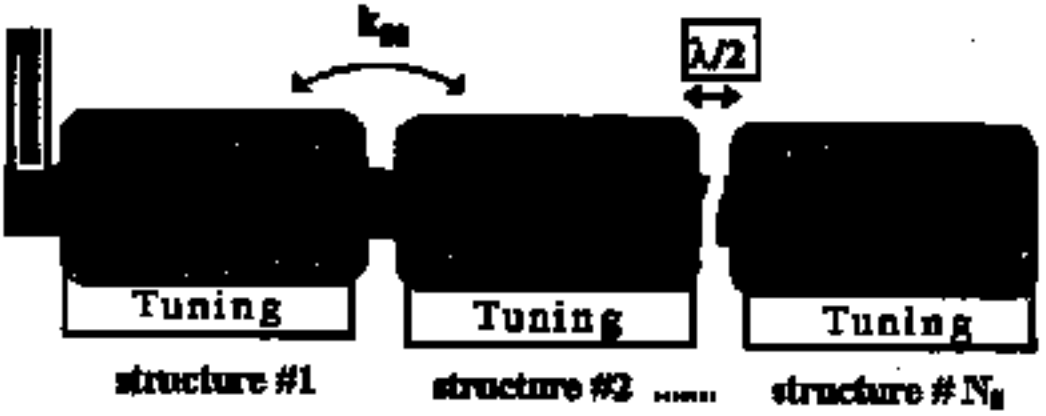

- requires 1-to-1 orbit correction ~ every 2 min.
- re-tuning (mainly: $D_y$) of system ~ every 2 months

Improvement of linac fill factor (CDR: $\eta_{fill} = 66\%$) with ***superstructure concept*** (J. Sekutowicz et al.)

present cavity spacing:




Superstructure: groups of ***coupled*** multi-cell cavities :




- increase fill factor → **76**...80% ( g (500GeV) = 21.7 MV/m)
- cost reduction: # input couplers ~ /4, rf-distribution system simplified

- improved efficiency: lower cryo losses @2K $\propto g/Q_0$ (assume $Q_0=10^{10}$), lower $Q_{ext}$ / shorter cavity filling time $\Rightarrow \eta_{AC\text{-}to\text{-}beam} = 17.3\% \rightarrow 23\%$

(note: could save half of cryo plant investment for initial 500 GeV stage of operation)

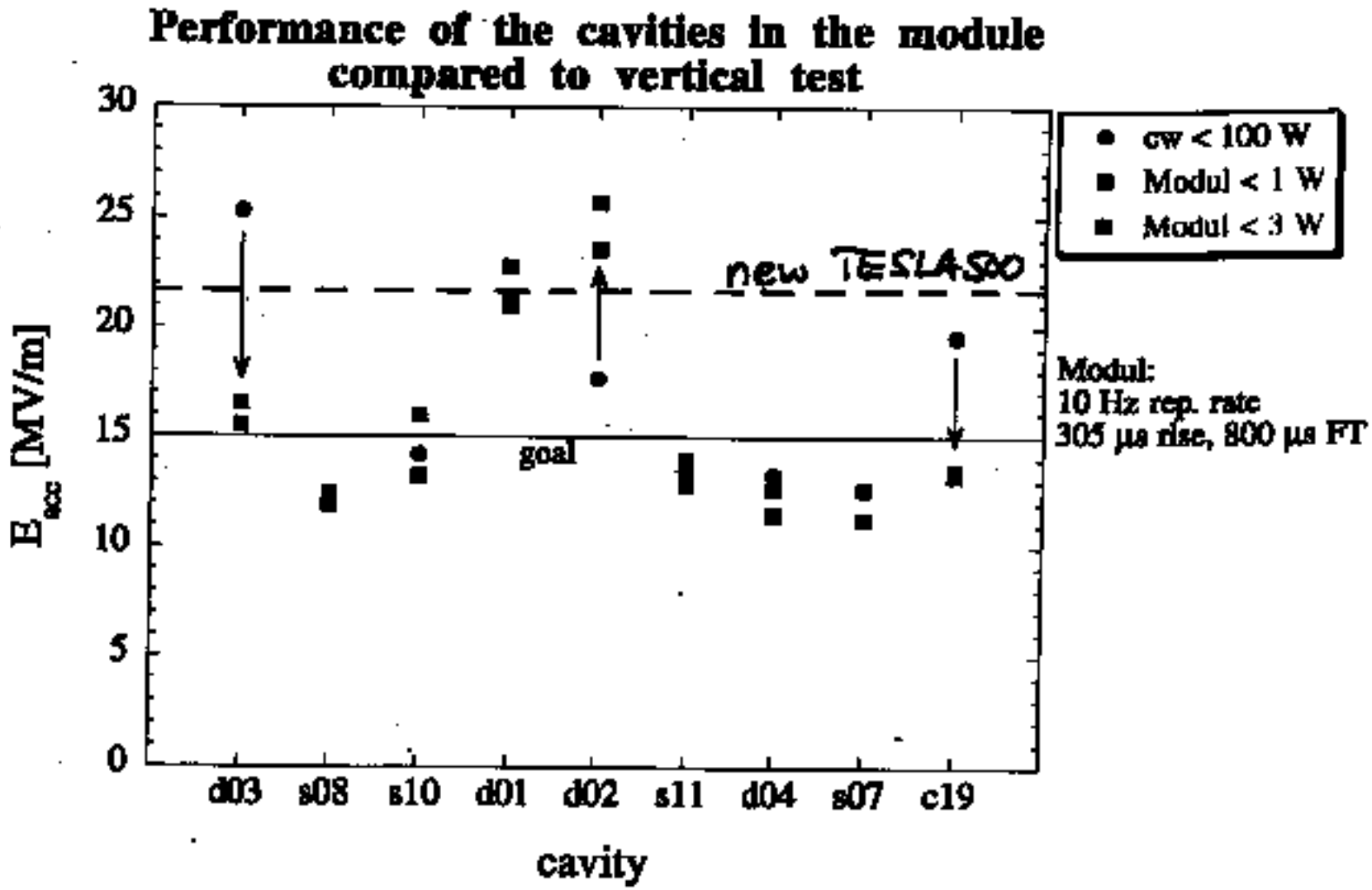
- invest cryo power savings into rf-power (by reduction of 10MW-klystron power reserve margin from 45%→20%)

**Energy upgrade:**

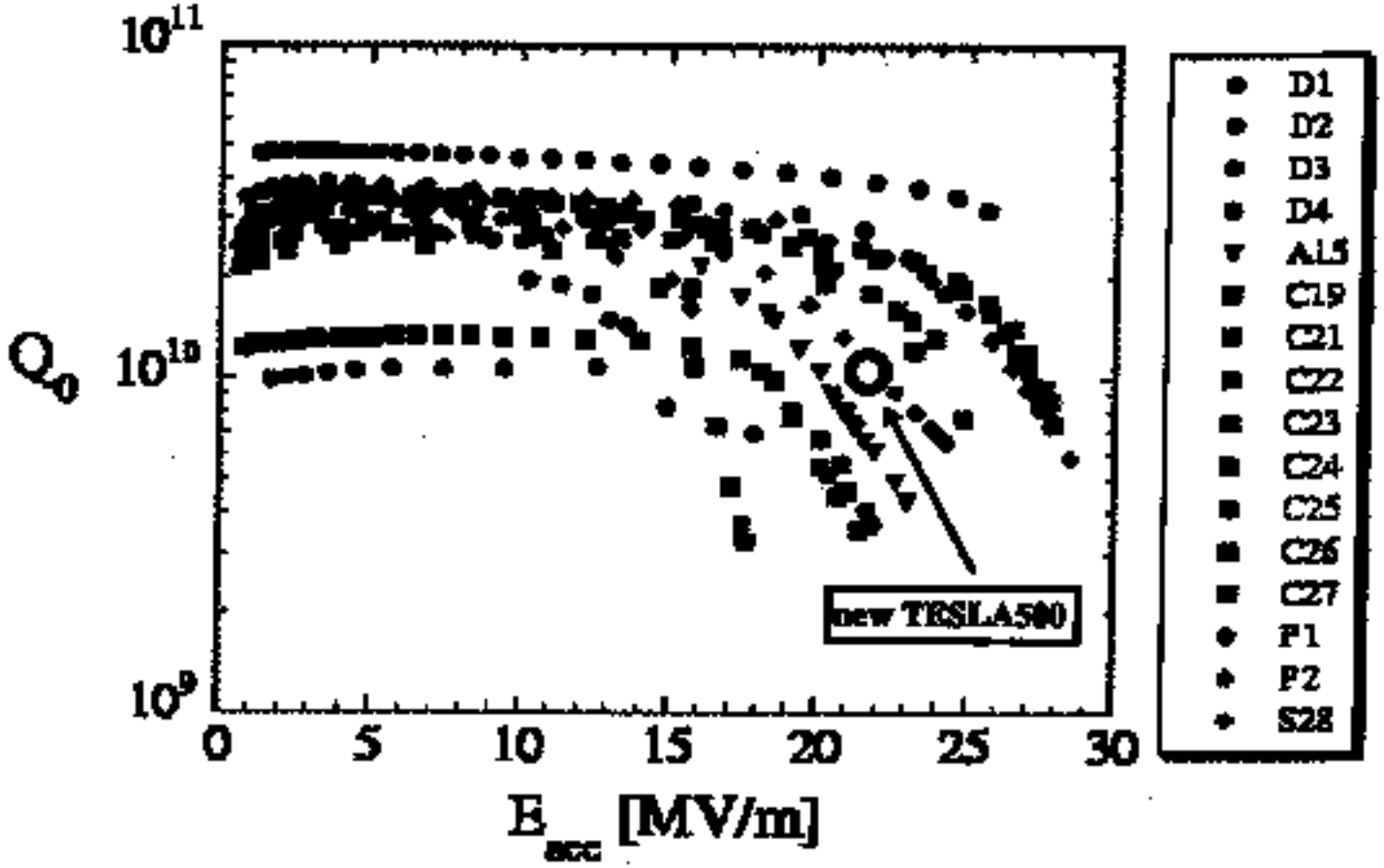
- $E_{cm} = 800$ GeV reached with $g = 34$ MV/m (will likely require exchange of modules with "bad" cavities with higher performance ones)

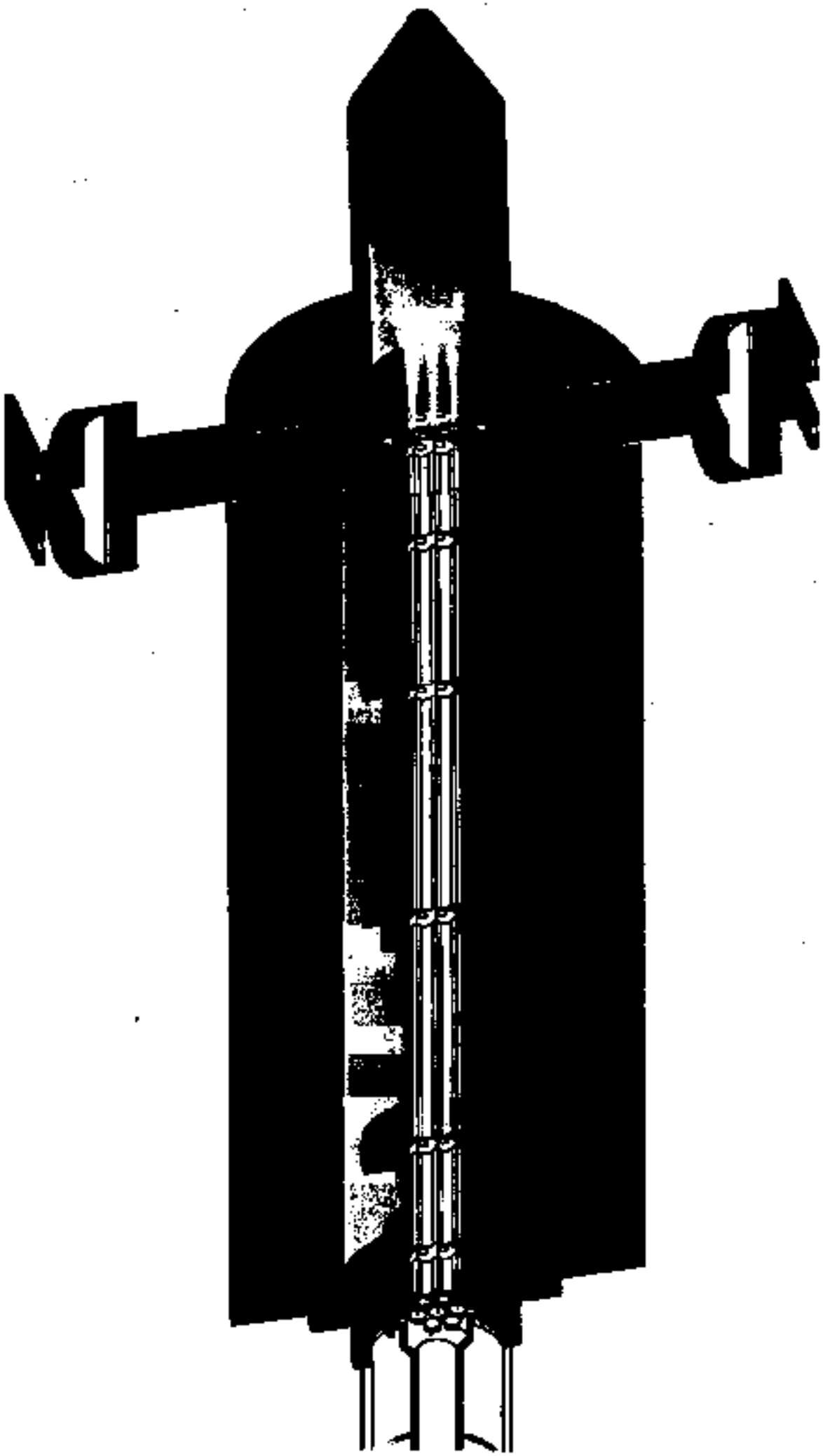
- double # of klystrons

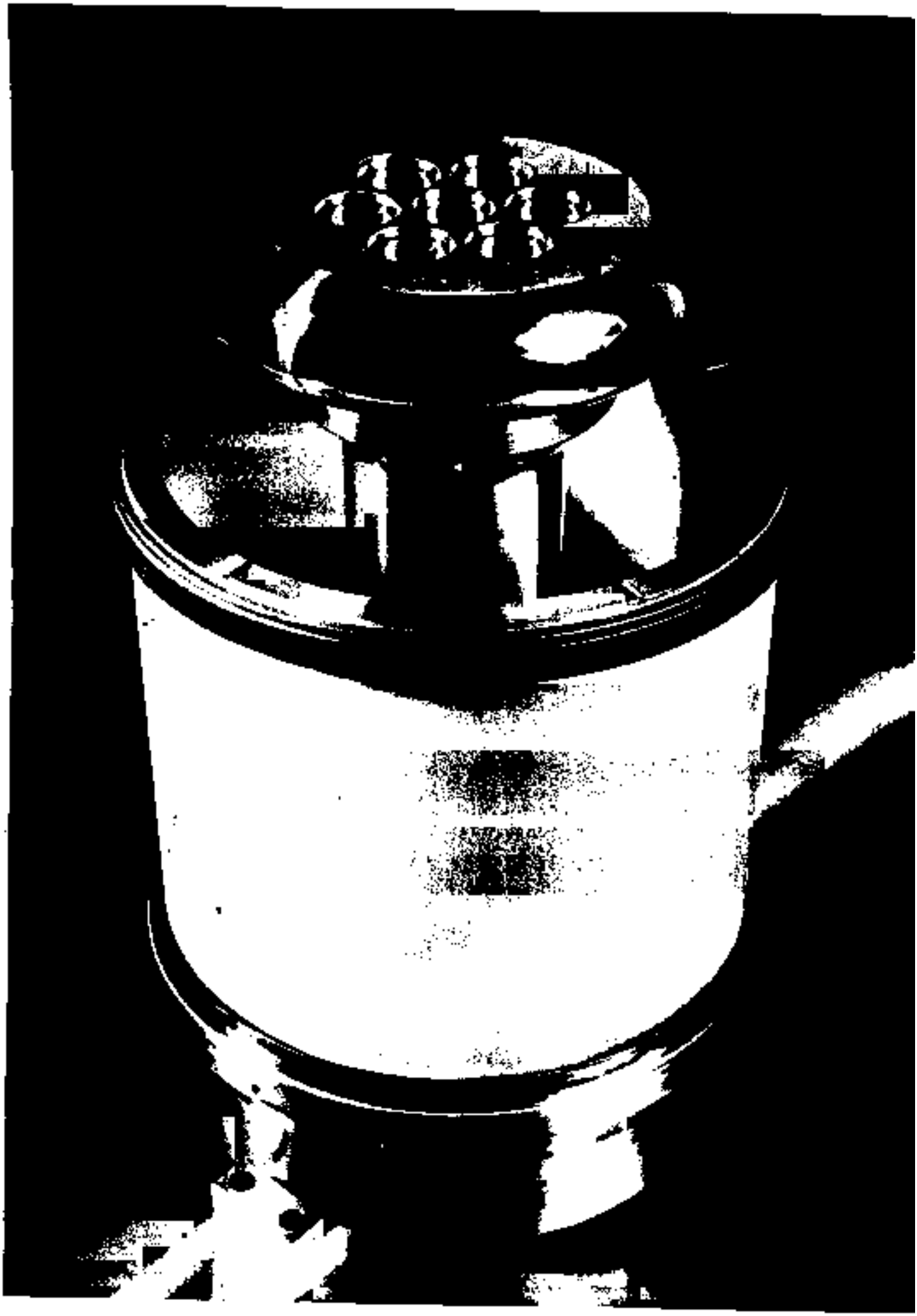
- operate cryo plants at full capacity incl. 50% safety margin of original design → $f_{rep}$ limited to 3Hz if $Q_0 = 5 \cdot 10^9$ @ 34 MV/m

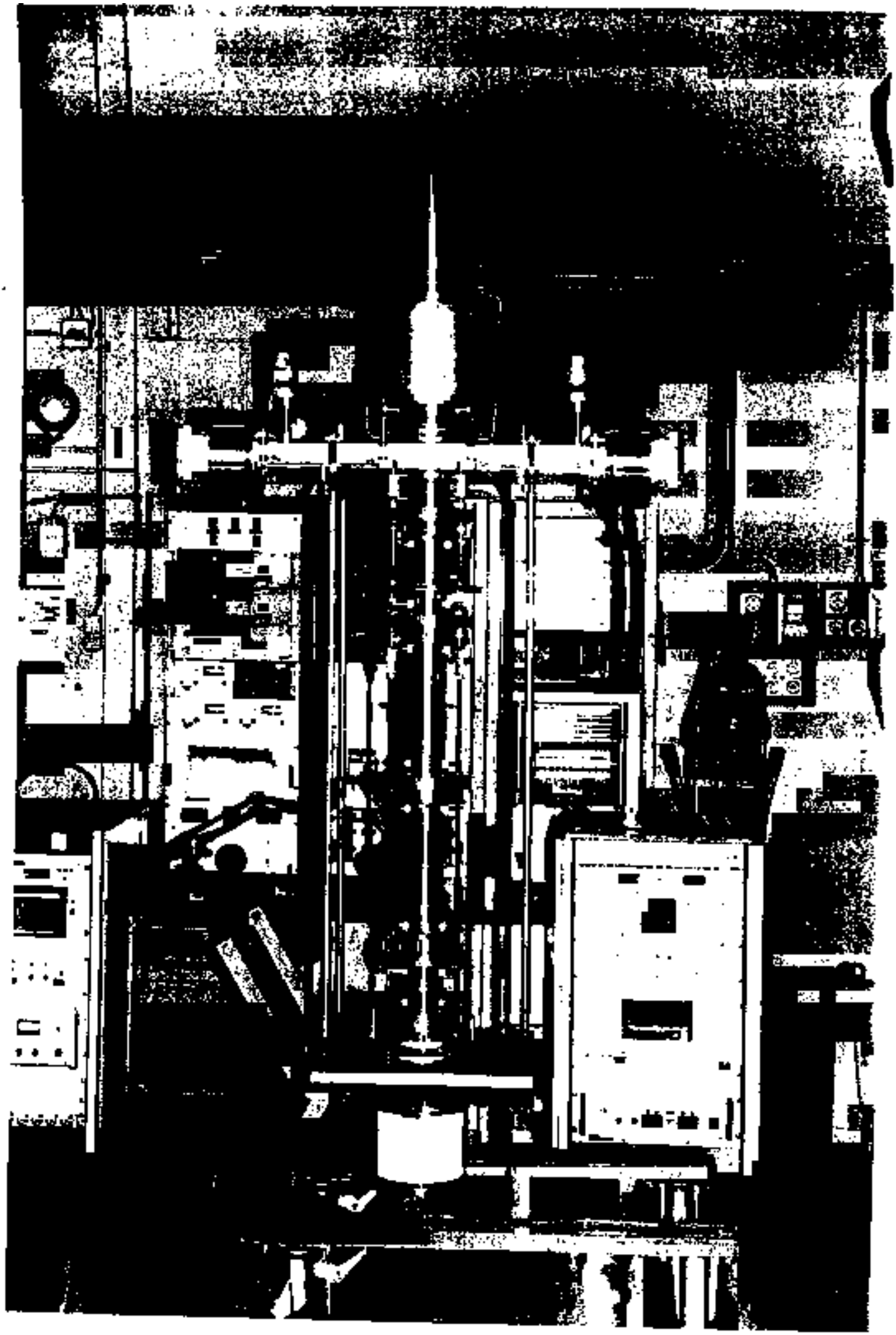

Performance of the cavities in the module compared to vertical test
30
25
20
15
10
5
0
$E_{acc}$ [MV/m]
new TESLA500
goal
cw < 100 W
Modul < 1 W
Modul < 3 W
Modul:
10 Hz rep. rate
305 µs rise, 800 µs FT
d03
s08
s10
d01
d02
s11
d04
s07
c19
cavity

Performance of TESLA cavities *without* obvious/well identified production errors









| | | | |
|---|---|---|---|
| **Frequency:** | **1300 MHz** | 1st test : | |
| **RF Pulse length:** | **1500 µs** | 400µs | |
| **Repetition rate:** | **10 Hz** | ✓ | |
| **Beam Voltage:** | **110 kV** | | |
| **Beam Current (total):** | **130 A** | | |
| **Perveance per beam** | **0.5*10-6** | | |
| **Drive Power:** | **200W max.** | | |
| **Output Power:** | **10MW peak** | **150kW average** | 10 MW / 20 kW |
| **Body Dissipation** : | **15kW max.** | | |
| **Efficiency:** | **> 70 %** | 65 % | |
| **Gain:** | **48 dB** | | |
| **Bandwidth (1 dB):** | **3MHz min.** | | |
| **No.of beams:** | **7** | | |

**Design parameters of the Thomson Multibeam-Klystron.**

**The gain of 48 dB means that the drive power is below 160 Watts. This power can be generated at low cost with solid state amplifiers.**

## Reduction of vertical emittance

- potential problem: large disruption ⇒ kink instability (if D > 15...20) (Chen, Yokoya 1980's)

- for given beam power

$$D_y = \frac{2N_e r_e \sigma_z}{\gamma \cdot \sigma_x \cdot \sigma_y} \propto L \cdot \sigma_z / \gamma$$

⇒ since $D_y = 18$ for ref. parameters, need reduction of $\sigma_z$

⇒ potential problems with D.R. and bunch compressor

**need a compromise !**

## Suggested new design parameters for TESLA

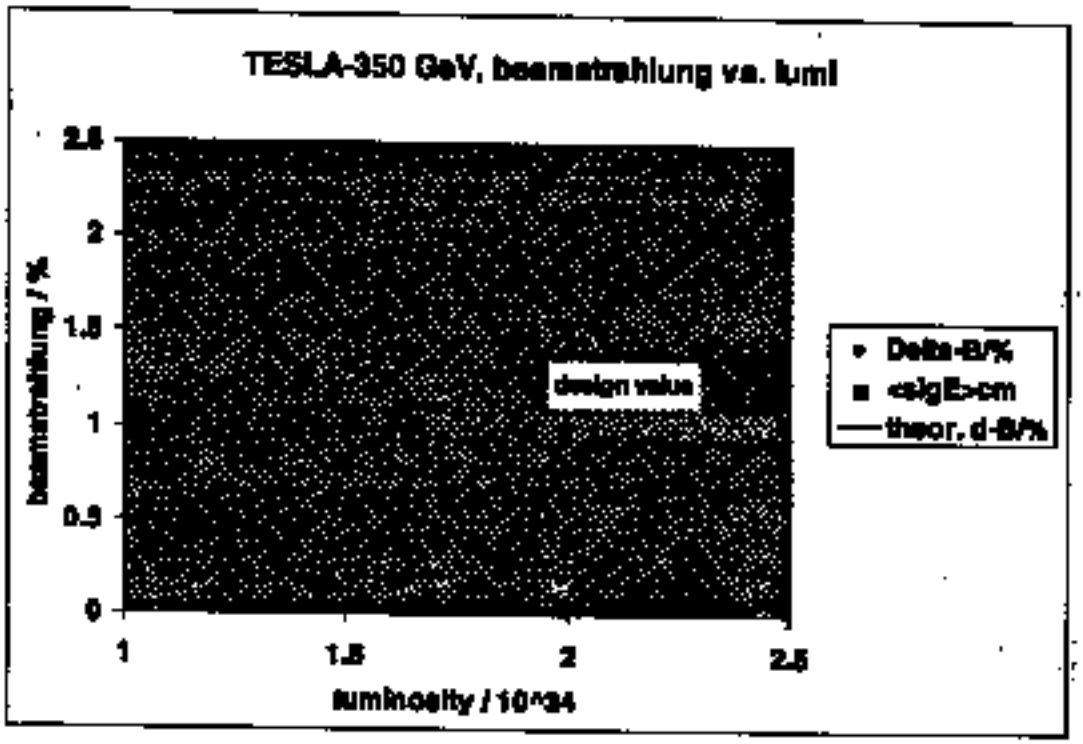
| | TESLA-500 | TESLA-800 | |
|---|---|---|---|
| site length | 32.6 | 32.6 | km |
| $t_{pulse}$ | 950 | 850 | μs |
| $n_b$/pulse | 2820 | 4500 | |
| $\Delta t_b$ | 337 | 189 | ns |
| $f_{rep}$ | 5 | 3 | Hz |
| $N_e$/bunch | 2 | 1.4 | $10^{10}$ |
| $\varepsilon_x$ / $\varepsilon_y$ (@ IP) | 10 / 0.03 | 8 / 0.01 | $10^{-6}$ m |
| $\sigma_x^*/\sigma_y^*$ | 553 / 5 | 391 / 2 | nm |
| $\sigma_z$ | 0.4 | 0.3 | mm |
| $\delta_B$ | 2.8 | 4.7 | % |
| Disr. $D_y$ | 33 | 39 | |
| $P_{AC}$ (2 linacs) | 95 | 132 | MW |
| luminosity L[1] | 3.1 | 5 | $10^{34}$ cm$^{-2}$s$^{-1}$ |

note: combination of smaller $\varepsilon_y$ with higher energy is not fundamental, but moderately advantageous (smaller $D_y$, linac emittance growth, # of damping times in D.R.)

[1] Including pinch enhancement and waist shift

## Operation near top-quark threshold

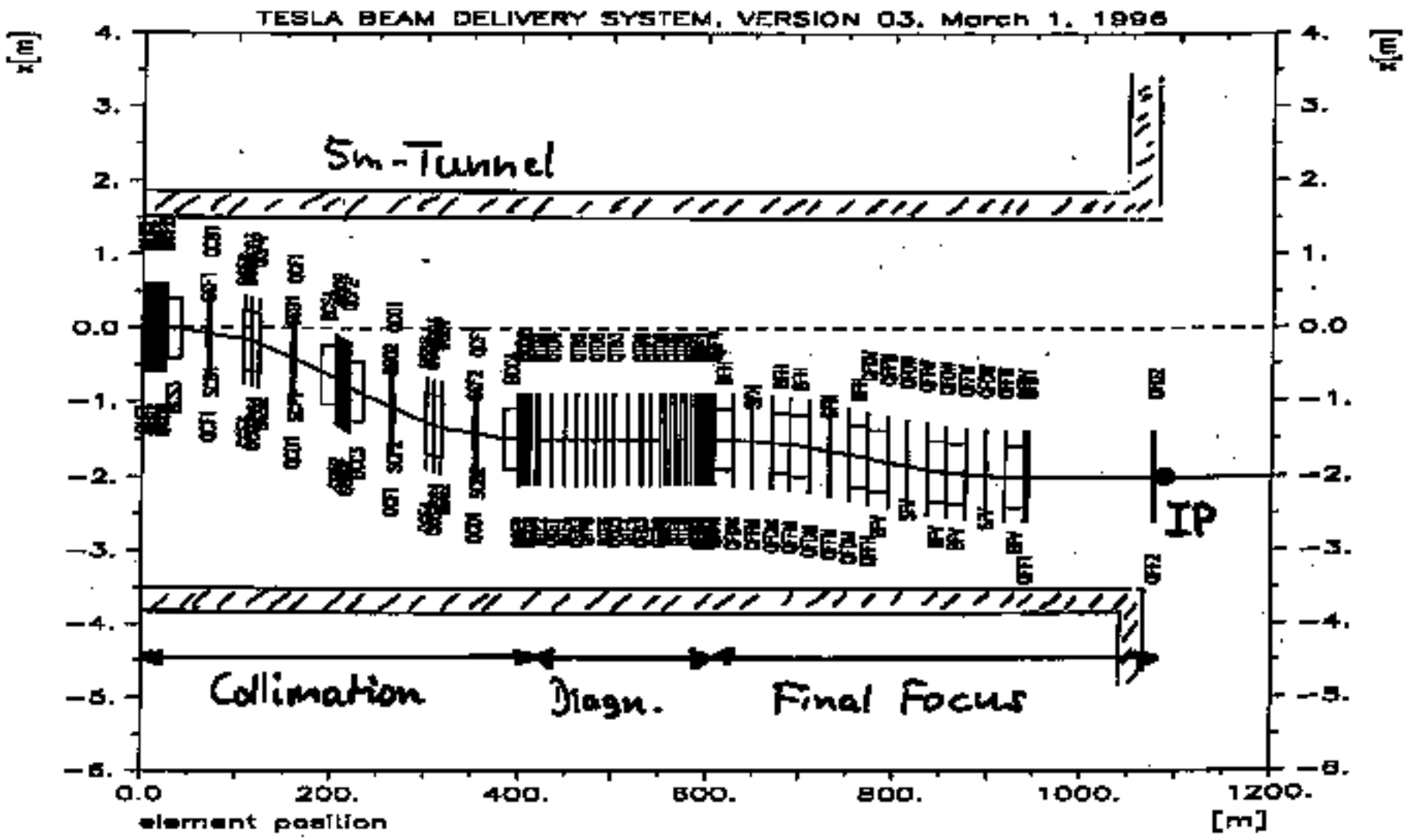
→ choice between high luminosity and low beamstrahlung by adjusting hor. Spotsize $\sigma_x$ at IP




note: AC-power is ~70 MW for this operation mode

Beam Delivery System / IR (O. Napoly, D. Schulte, N. Walker, R.B.)

- smaller β-function at IP ok without system modification
- tighter requirements for IP-feedback with larger $D_y$
- Luminosity scan (using Bremsstr. e+e-) within < one pulse possible
- tight requirements for beamsize instrumentation (Shintake-mon., laser wires, ...)
- spot size stabilisation with orbit feedback ok for 1μm BPM-resolution
- collimator protection critical- possible "sextupole-spoiler" under study (vertical aperture is up to $170\sigma_y$!)




SYSTEM FOR $E_{cm} = 800$ GeV

[NLC-SYSTEM $L = 2 \times 5$km, $E_{cm}$ up to 1.5 TeV]

TESLA

HEAD-ON COLLISION SCHEME

WITH S.C. FINAL DOUBLET

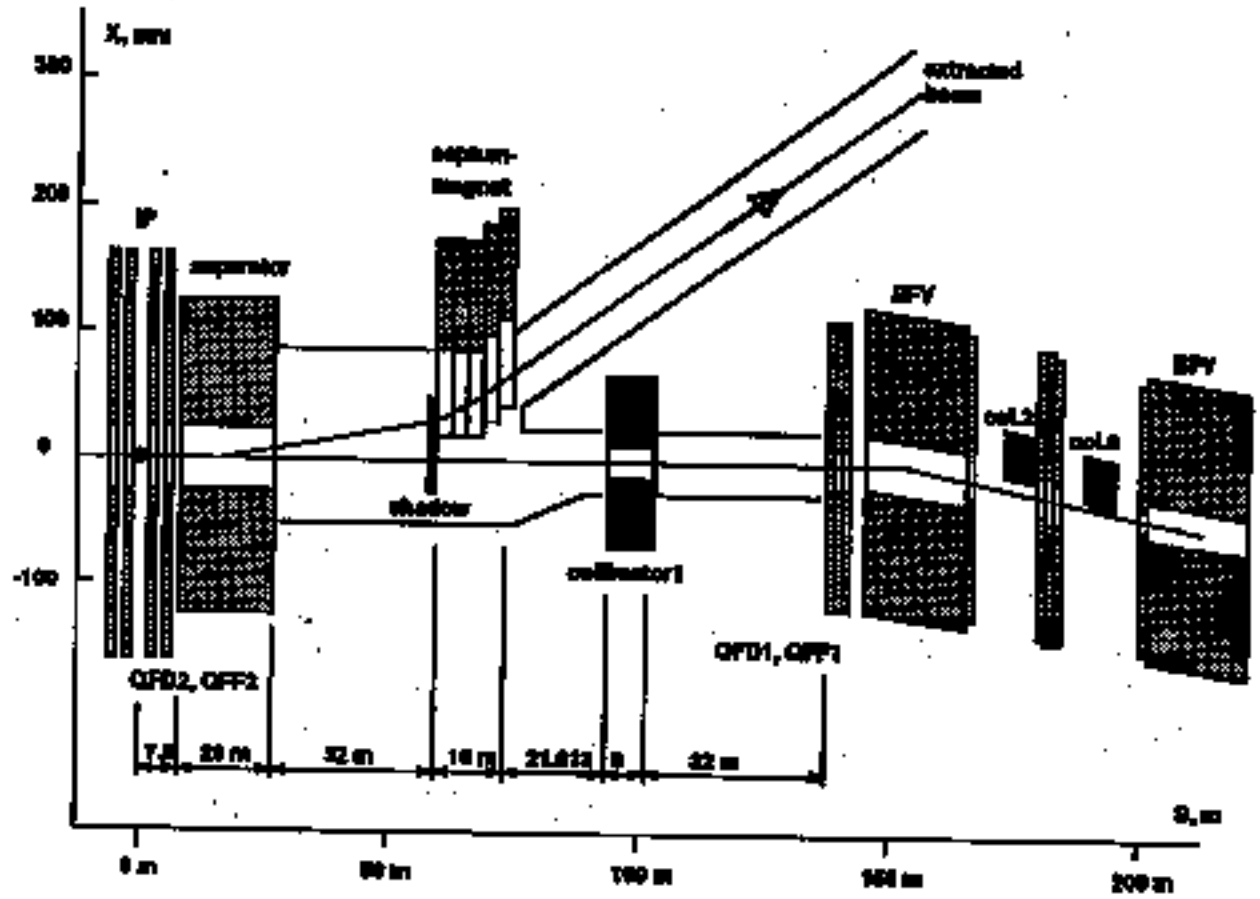
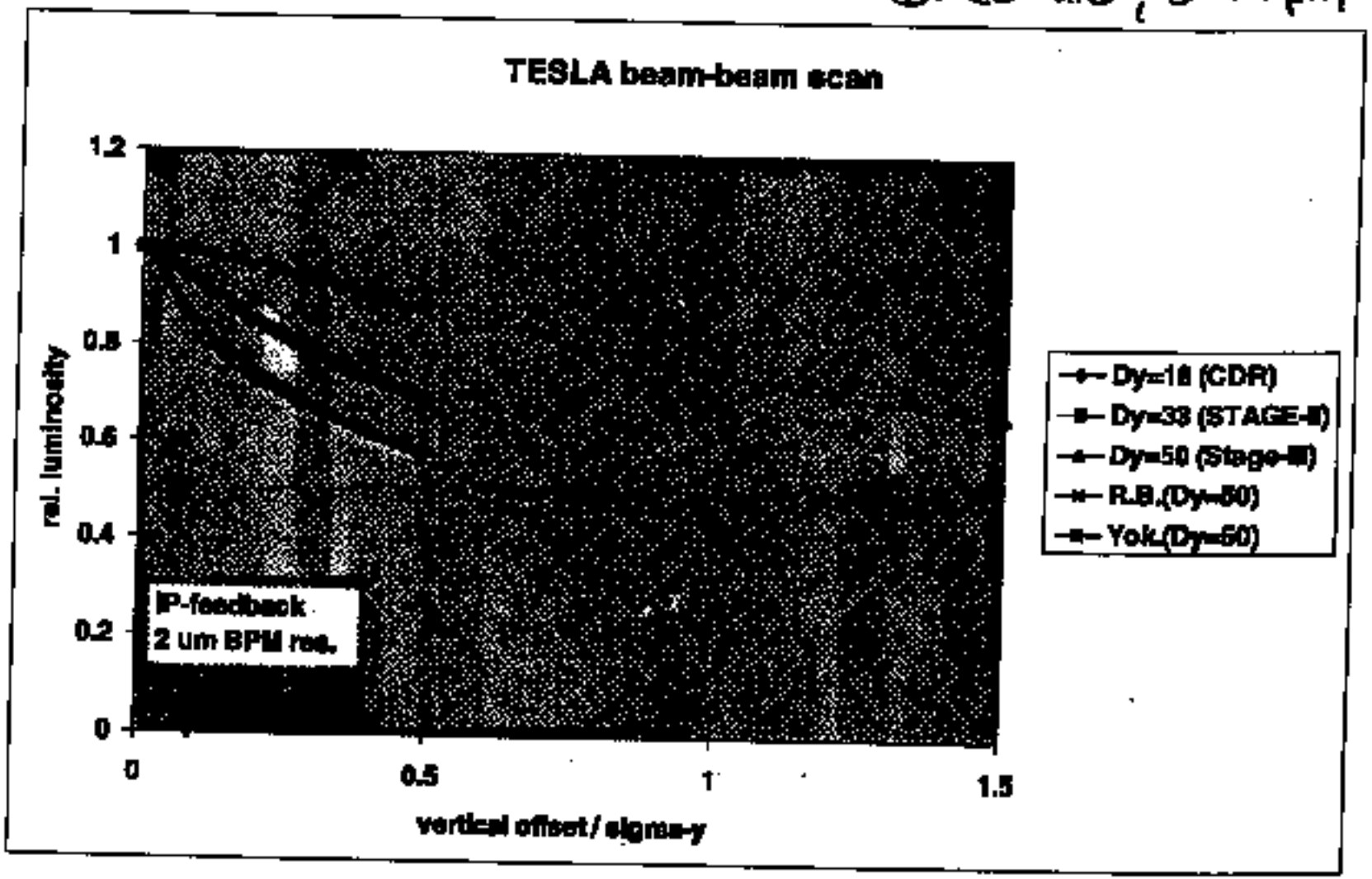
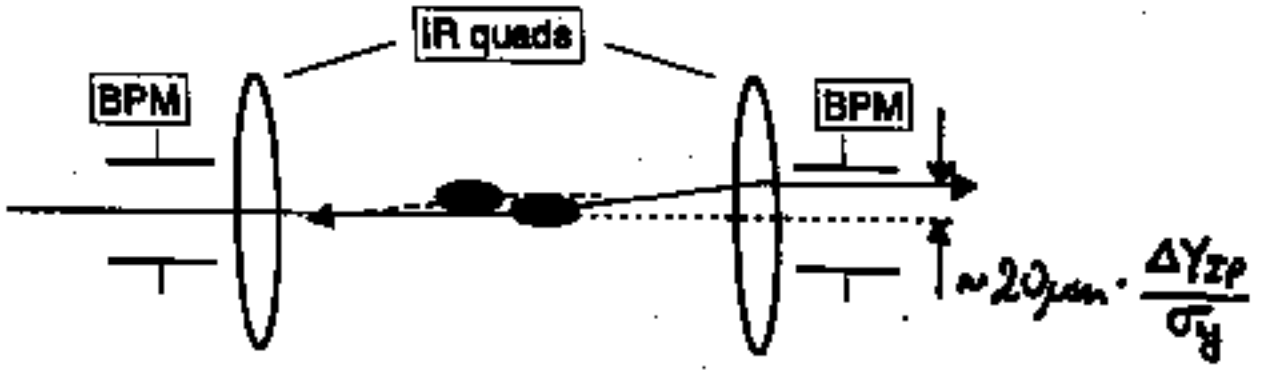


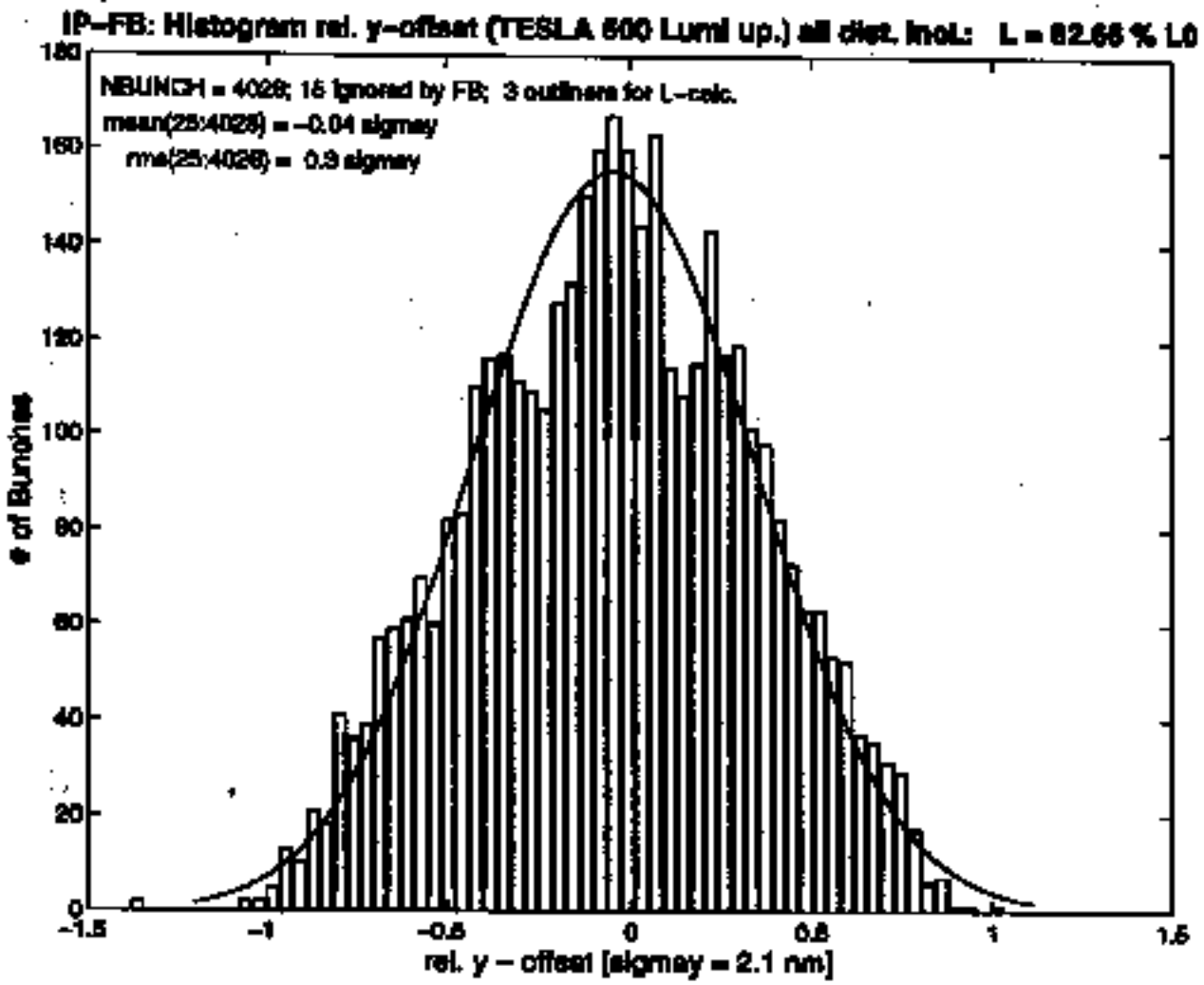

Figure 3.18: Layout of the beam extraction system after the IP.

D. Schulte, O. Napoly



T. Reyl

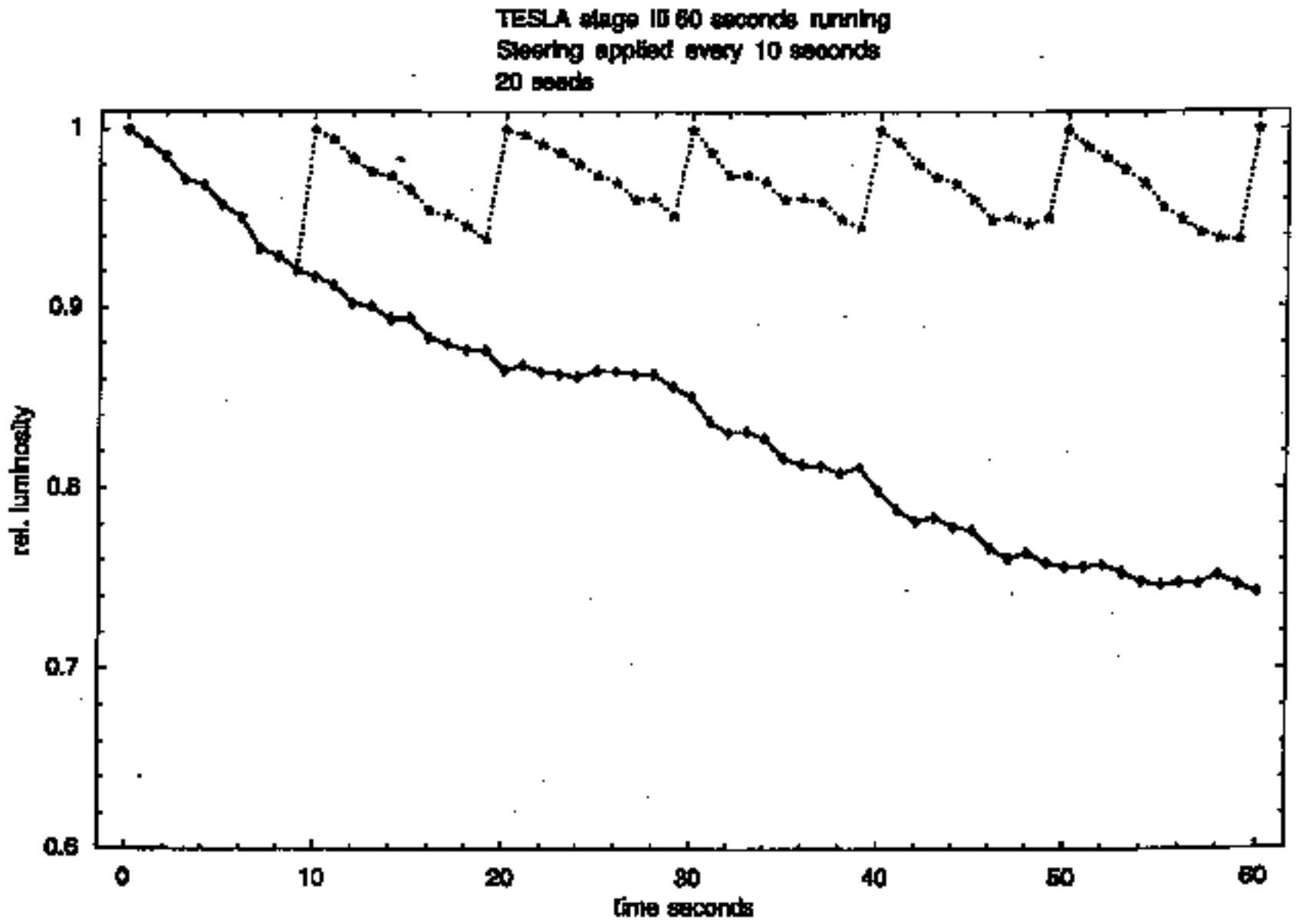



Simulation of IP - Feedback for $\sigma_y = 2nm$

(using 10μm BPM resolution)

$\sigma_y = 2nm$ , ATL – Model (N. Walker)



## Main Linac Beam Dynamics (A. Mosnier)

- assumption: same tolerances as in CDR (0.5mm r.m.s. for cavity and quad position errors), beam-based BPM-to quad alignment with 10μm r.m.s. resolution

- single bunch emittance growth:

TESLA-500: $\Delta\varepsilon_y / \varepsilon_y = 23.8\ \%$

TESLA-800: $\Delta\varepsilon_y / \varepsilon_y = 35.9\ \%$
(scaled from a 500GeV simulation result)

- multi-bunch emittance growth:

TESLA-500: $\Delta\varepsilon_y / \varepsilon_y = 23.8\ \%$

TESLA-800: $\Delta\varepsilon_y / \varepsilon_y = 56\ \%$
(scaled from a 500GeV simulation result)

reduction with fast kickers (few MHz bandwidth) possible (under study)

TESLA: Damping Ring (E=3.2 GeV)

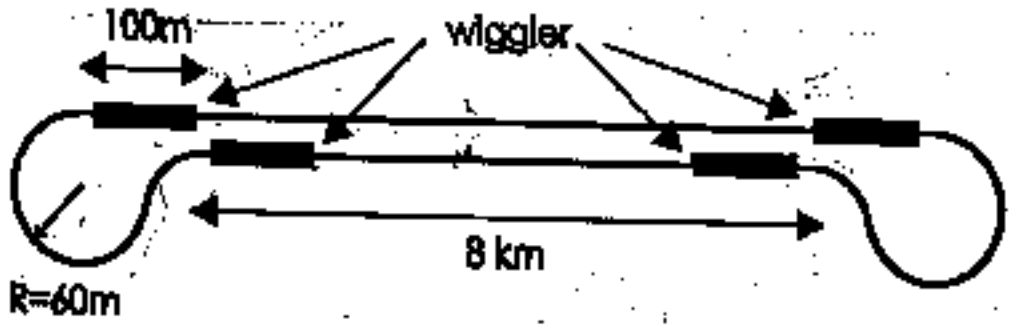



Figure 3.1: General layout of the "dogbone"-shaped damping ring

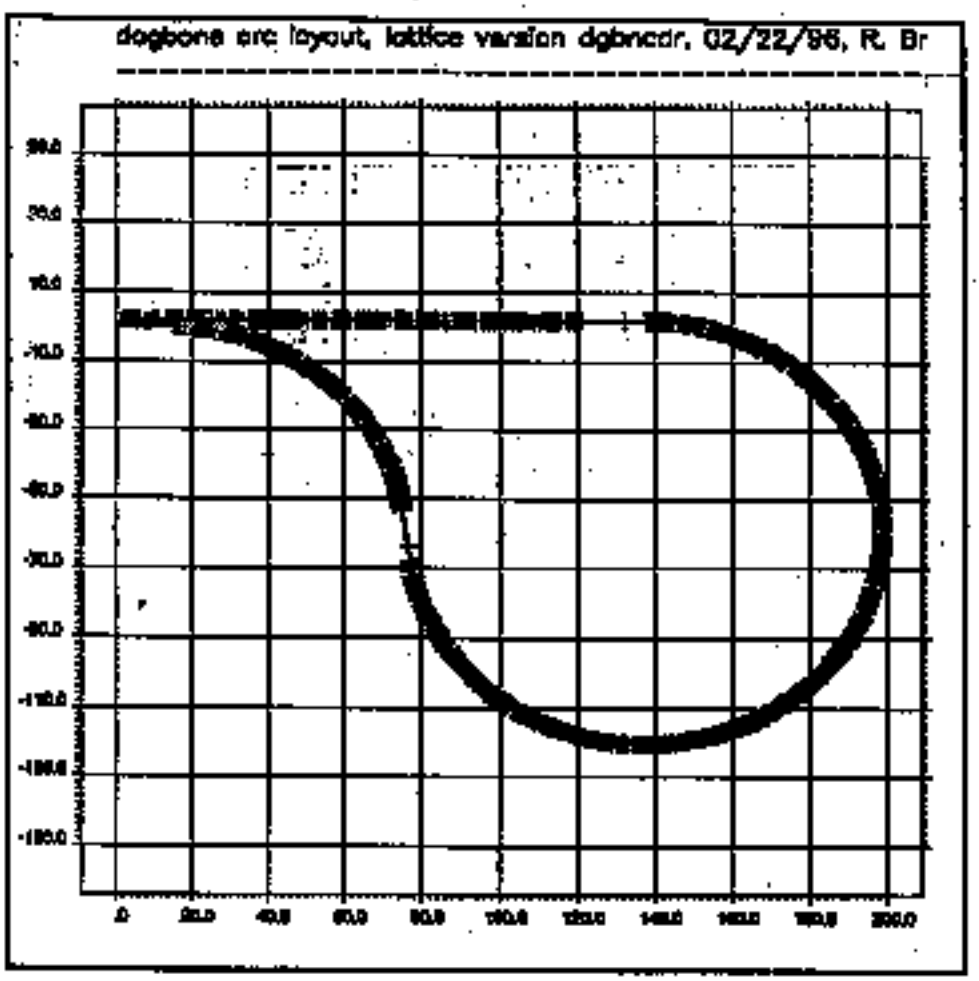



Figure 3.2: Geometry of the "dogbone" damping ring arcs

## Damping Ring / Bunch Compressor

- would like to (probably have to!) avoid 2nd stage compressor ⇒ demand for shorter bunch in D.R. ***in addition*** to smaller $\varepsilon_y$

- not a problem from single bunch instabilities (simulation results by C. Burnton), but:

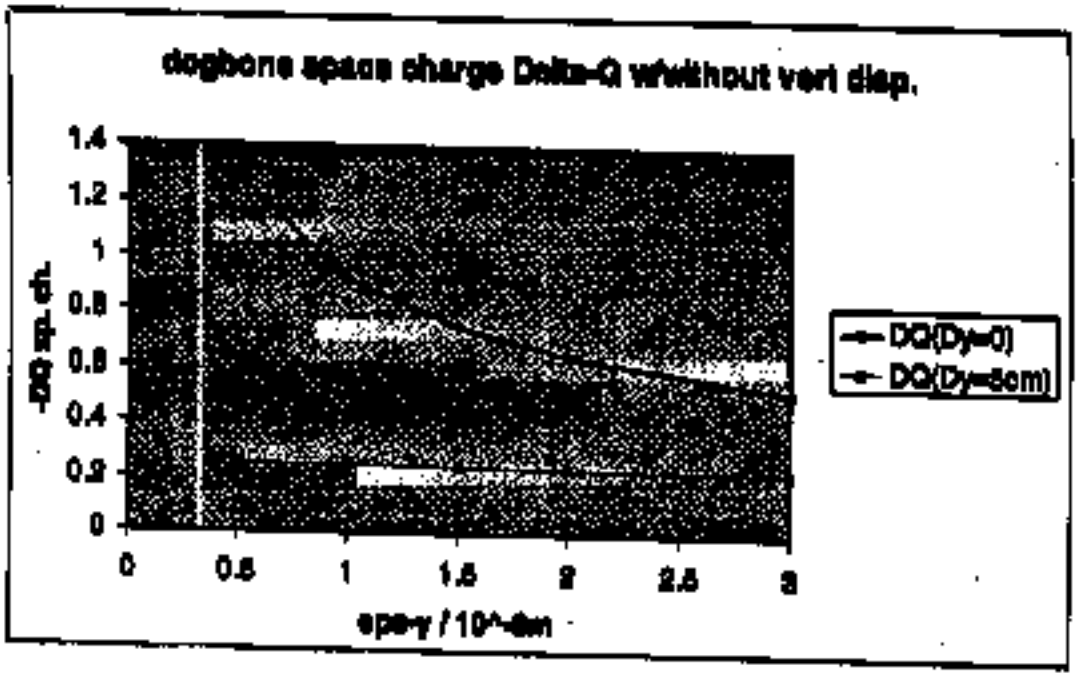
- incoherent space charge tune shift becomes a serious limitation (for 17km long dogbone design):

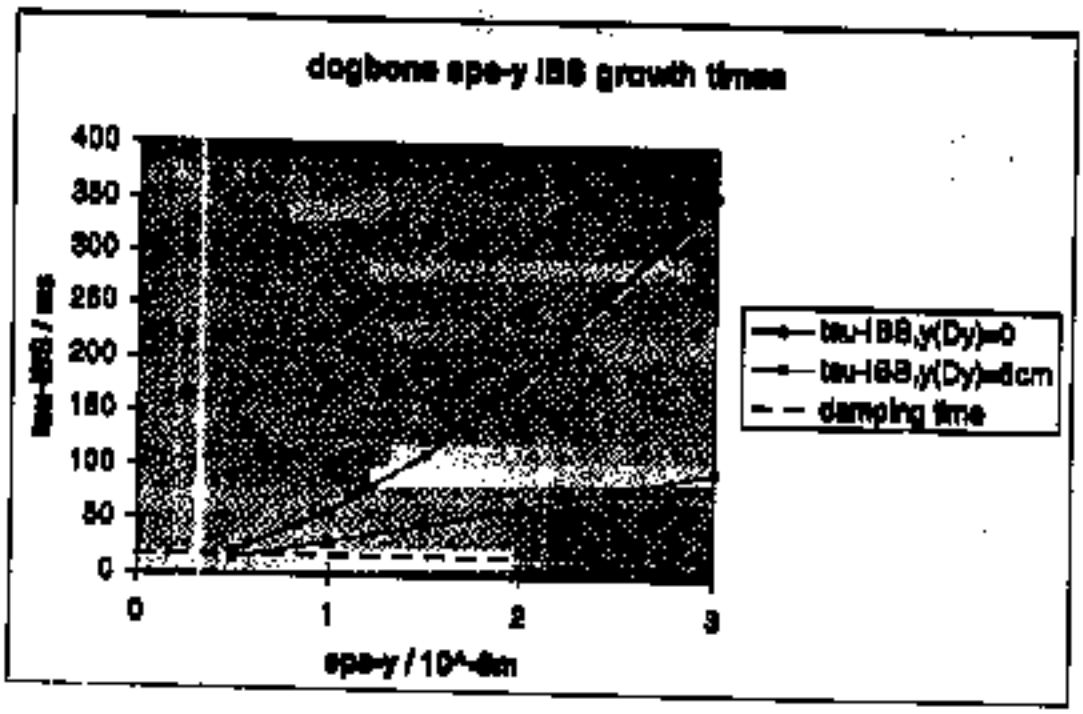
$$\Delta Q_{incoh} \approx C_{DR} \cdot \frac{N_e r_e}{(2\pi)^{3/2} \gamma_{DR}^2 \sigma_z (\varepsilon_x \varepsilon_y)^{1/2}} \approx -0.17 (ref.design)$$

decrease $C_{DR}$? Bunch spacing already approaches reasonable lower limit (~10ns) for TESLA-800 (could build several shorter rings…)

increase energy? Emittance from arcs scales $\propto \gamma_{DR}^6$

- proposed solution (N. Walker): reduce charge density in straight sections (95% of the ring!) by introducing finite dispersion


dogbone space charge Delta-Q without vert disp.
-DQ sp. ch.
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
spe-y / 10^-6m
DQ(Dy=0)
DQ(Dy=6cm)


dogbone spe-y IBS growth times
tau-IBS / ms
400
350
300
250
200
150
100
50
0
0
1
2
3
spe-y / 10^-6m
tau-IBS,y(Dy)=0
tau-IBS,y(Dy)=6cm
damping time

$$\Delta Q_y \rightarrow \Delta Q_y / (1+\gamma \cdot \frac{\sigma_E^2}{\varepsilon_y}\left\langle D_y^2 / \beta_y \right\rangle_{av})^{1/2}$$

- with $\sigma_E = 0.1\%$, need ~5cm (rms) vertical dispersion to cure the space charge problem

- drawback: stronger effect of intrabeam scattering (IBS) on $\varepsilon_y$ (K. Balewski, based on Piwinski's theory)

| | CDR-design | new TESLA500 | new TESLA800 |
|---|---|---|---|
| $N_e$ $[10^{10}]$ | 3.6 | 2 | 1.4 |
| # bunches | 1130 | 2820 | 4500 |
| $\Delta t_B$ [ns] | 50 | 19 | 12 |
| $\varepsilon_{x,y}$ $[10^{-6}$ m] | 12, 0.2 | 8, 0.02 | 6, 0.007 |
| $\Delta Q_y$ | -0.17 | -0.20 | -0.23 |
| $\tau_{d,y}/\tau_{IBS}$ | 0.01 | 0.26 | 0.8 |

**Comment#1: A design optimisation of the D.R. and extensive studies of dyn. Aperture, tolerances & correction procedures, Ion-capture, etc. should be done**

**Comment#2: the goal for $\varepsilon_y$ goes beyond state-of-the art! I strongly recommend to start experiments at existing rings (HERA ideal, but unlikely available, PETRA seems well suited)**

## Positron Source

- new parameters with smaller $\sigma_z$ are advantageous (reduced spent beam emittance) → spent beam capture efficiency > 90%

- chances for polarised source improved, but still very ambitious

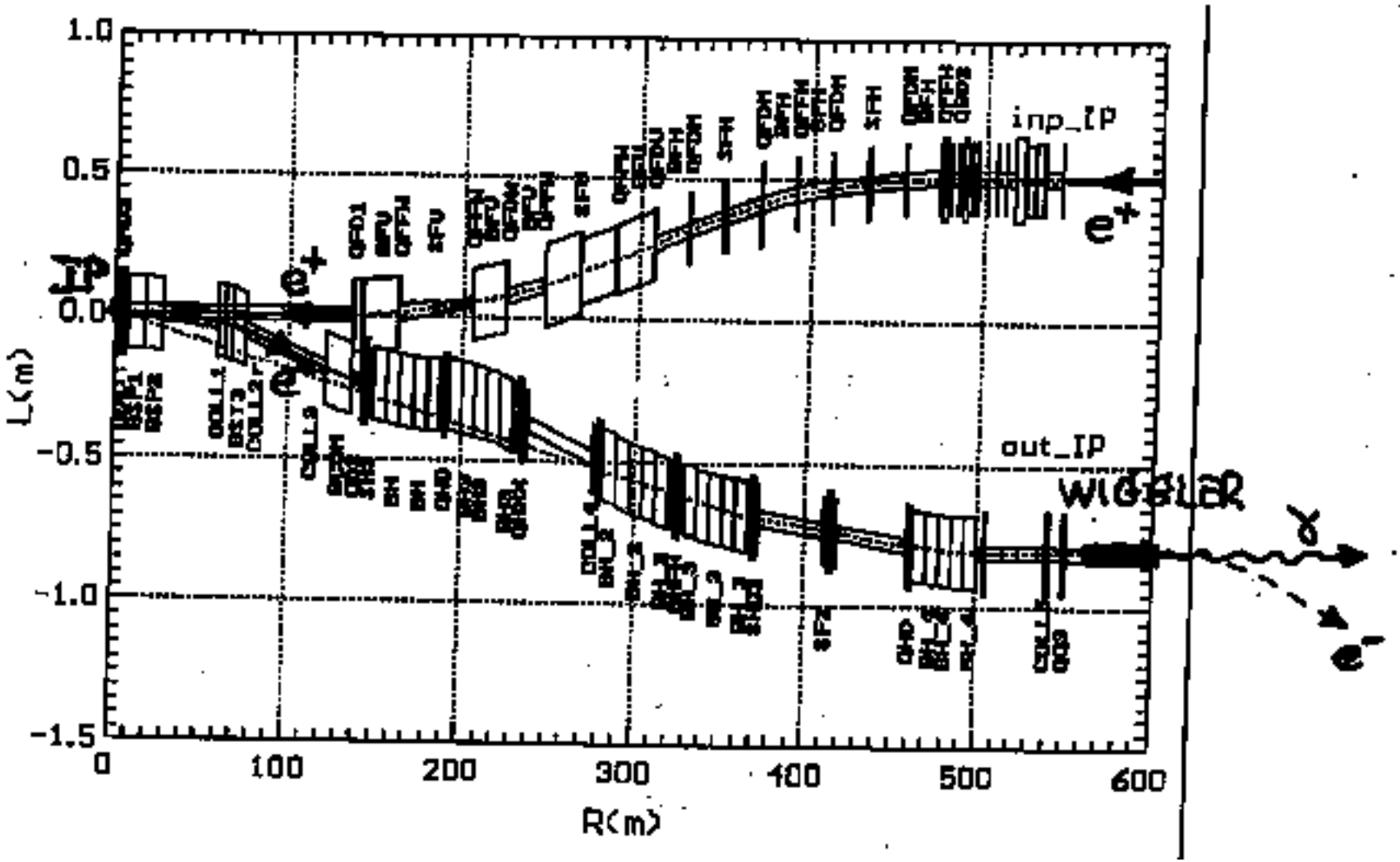
- spent beam collimation is being investigated (E. Merker et al.), heat load from several 100kW beam loss per collimator seems close to tolerable limit

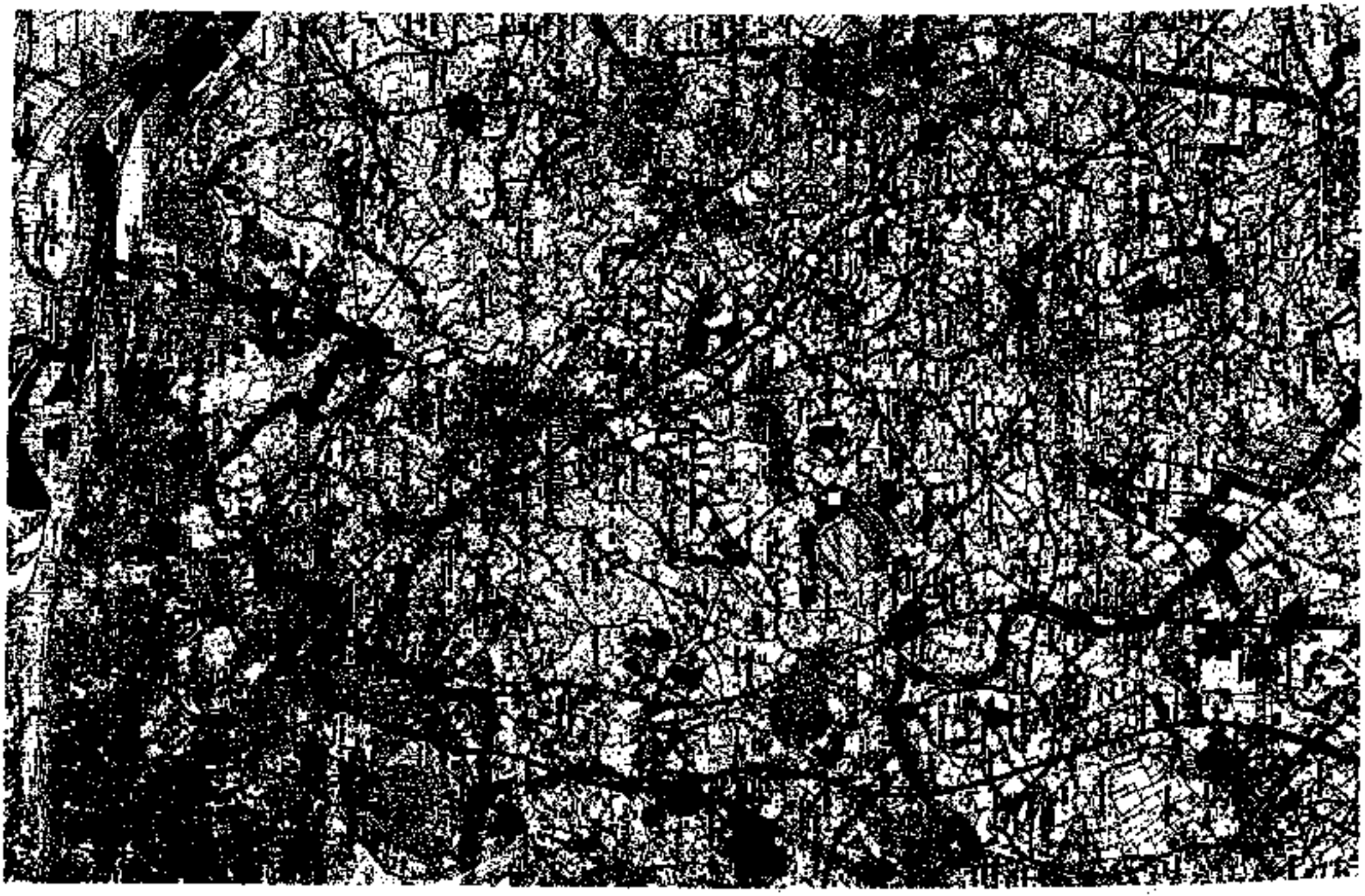
- technical layout of target area and injector linac still missing

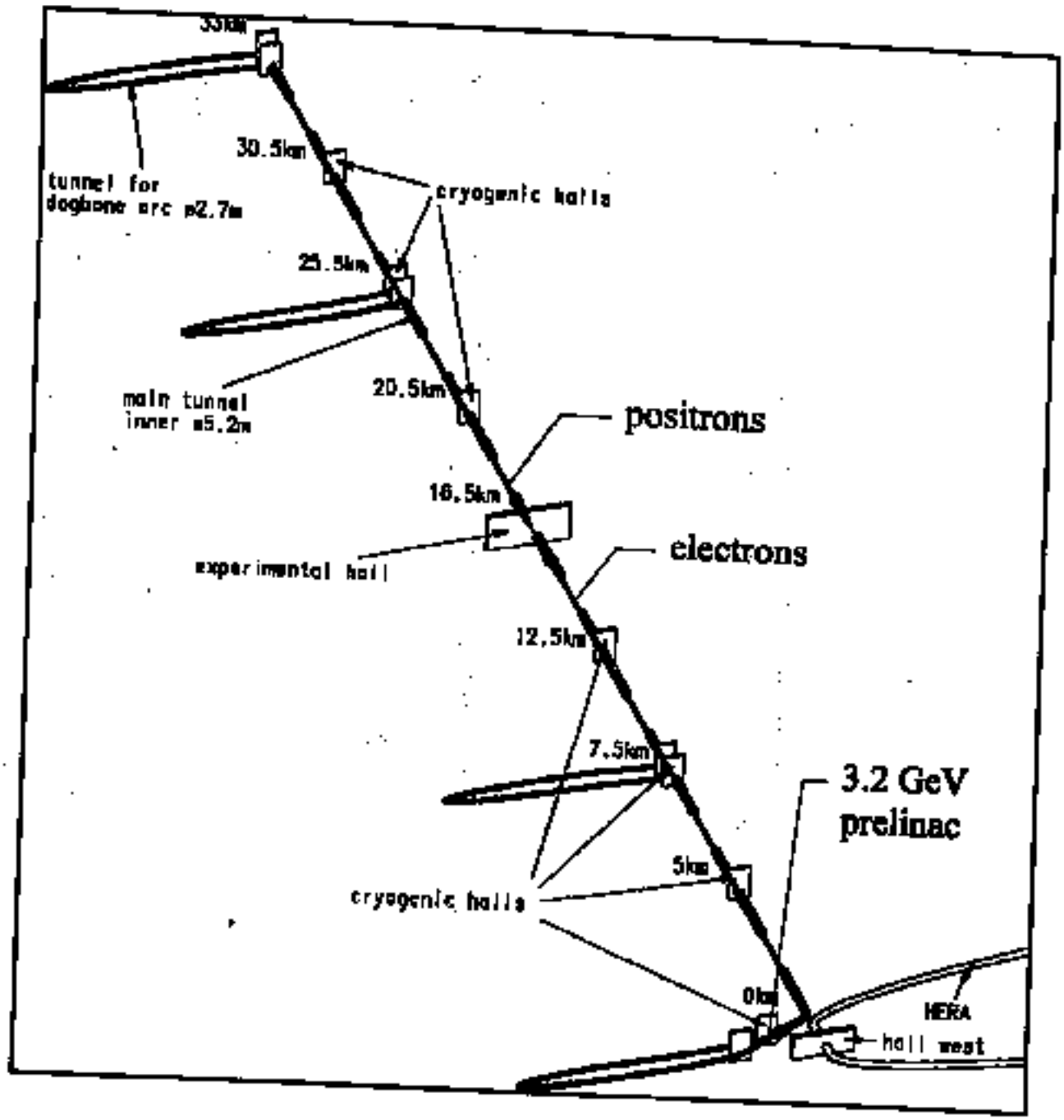
# OPTIMISATION OF POSITRON SOURCE

$e^-$ SPENT BEAM CAPTURE EFFICIENCY 85% → 93%

(76 % POLARISED SOURCE)



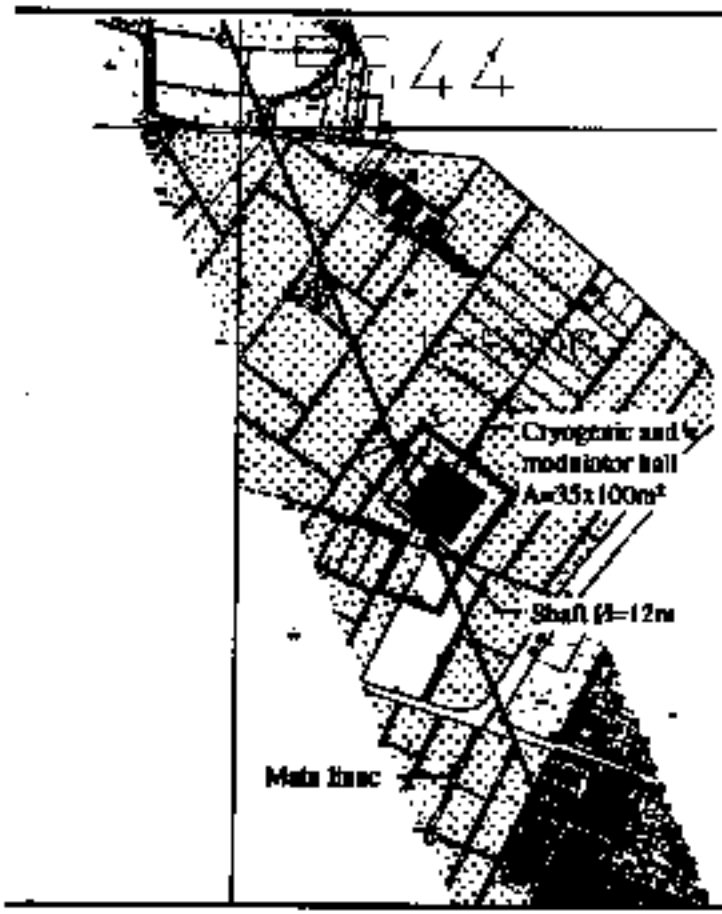




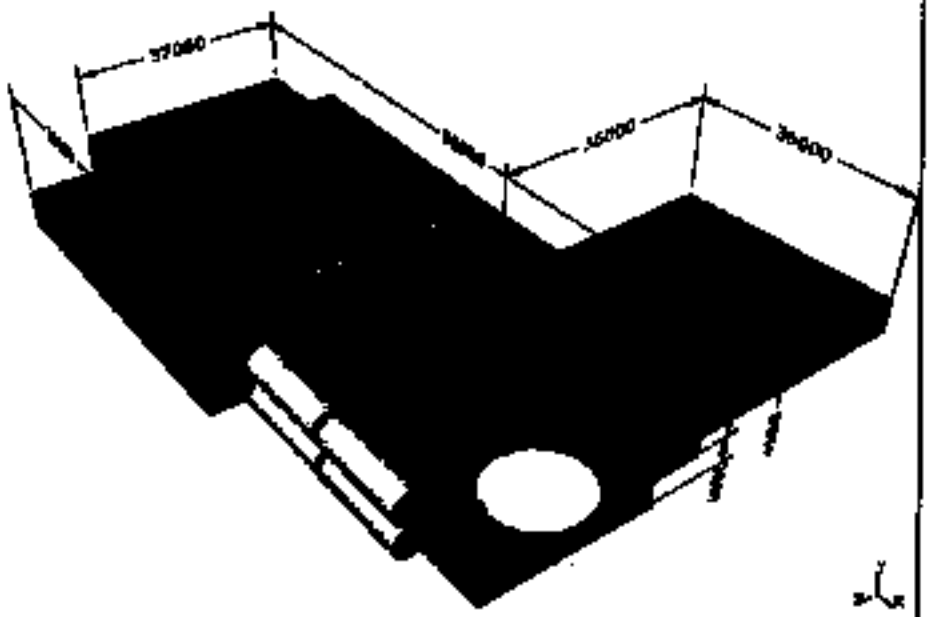

Overall layout of the TESLA linear collider.

# Linear Collider



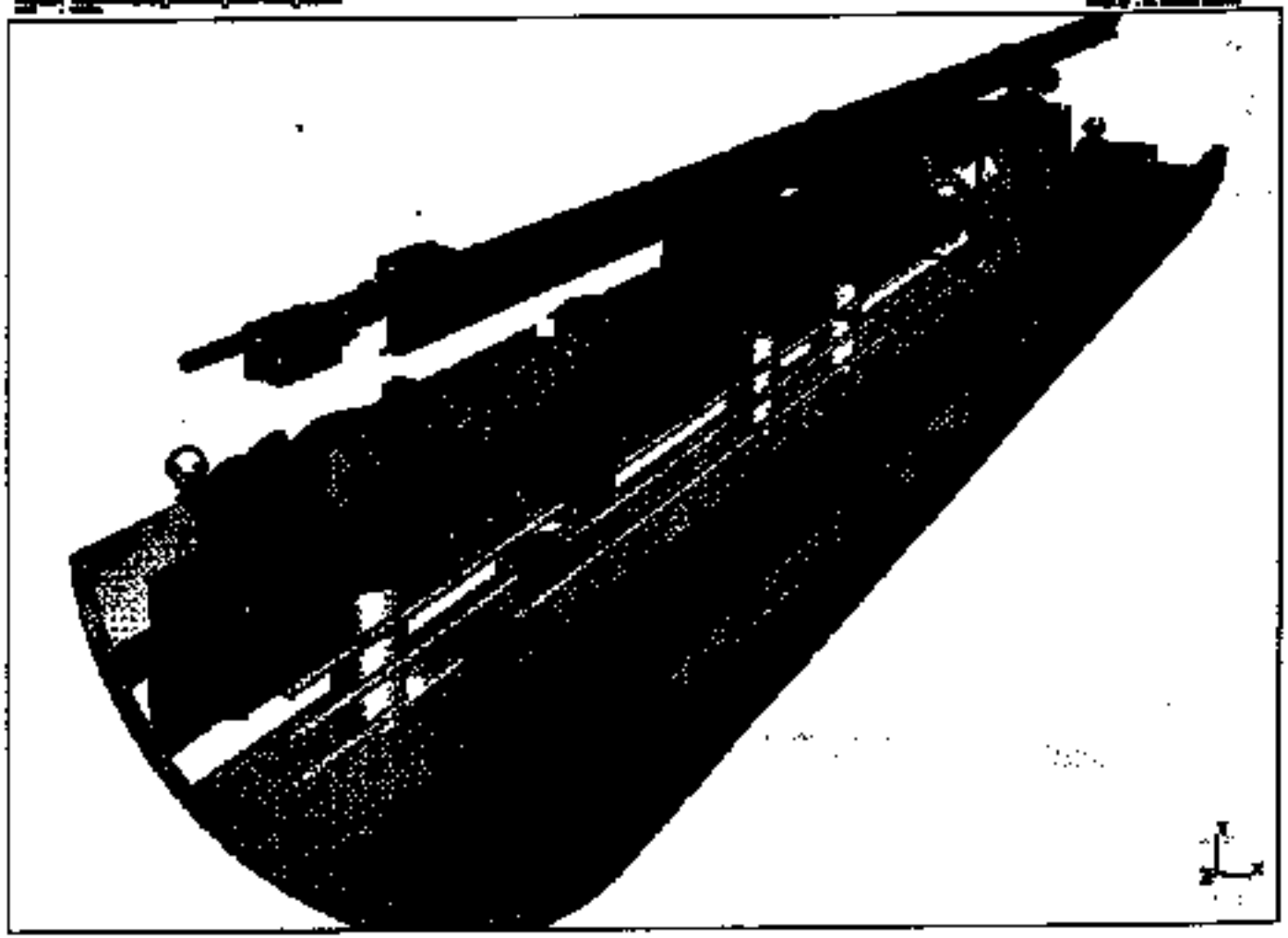


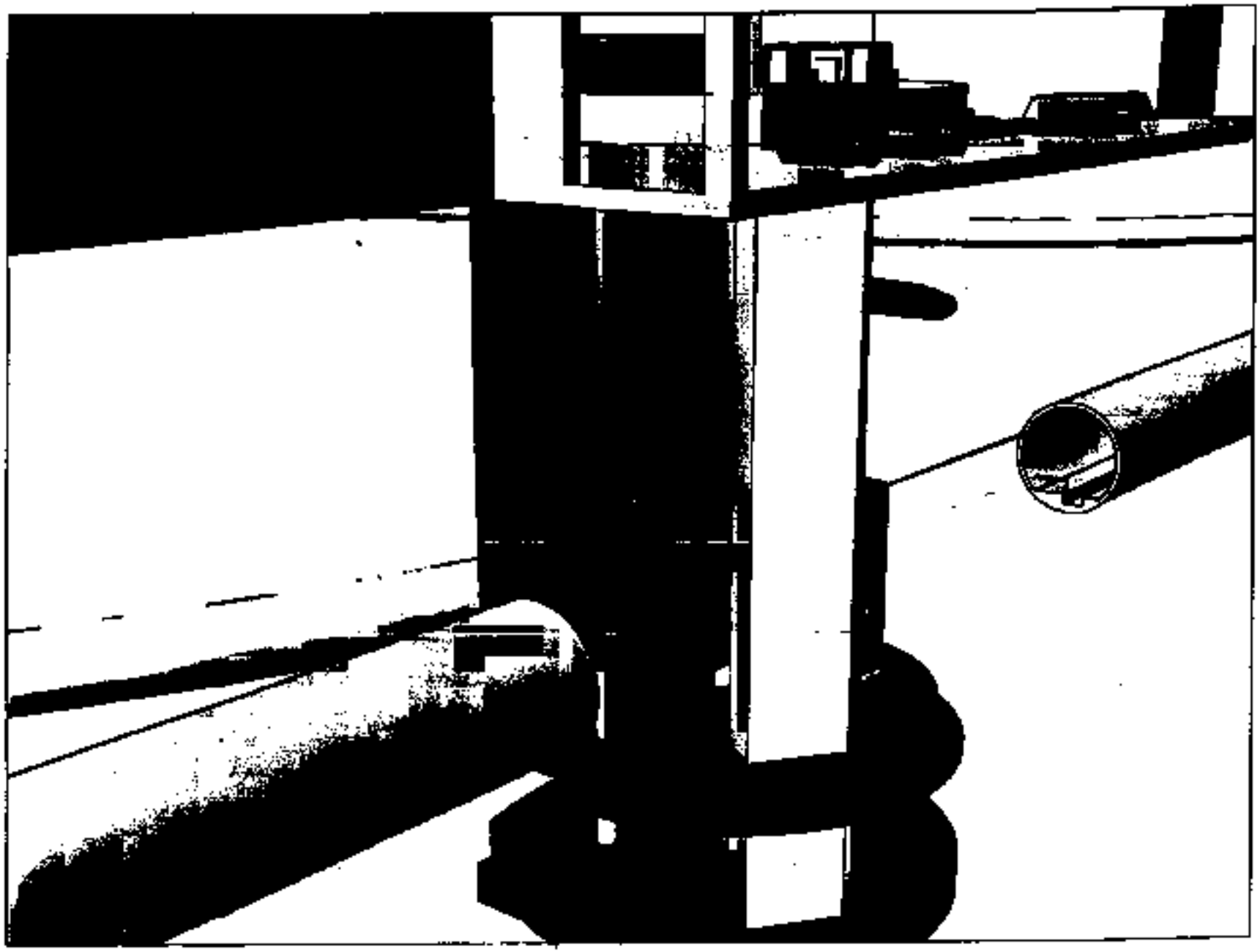

Area for a cryogenic plant.




First layout of a cryogenic hall.

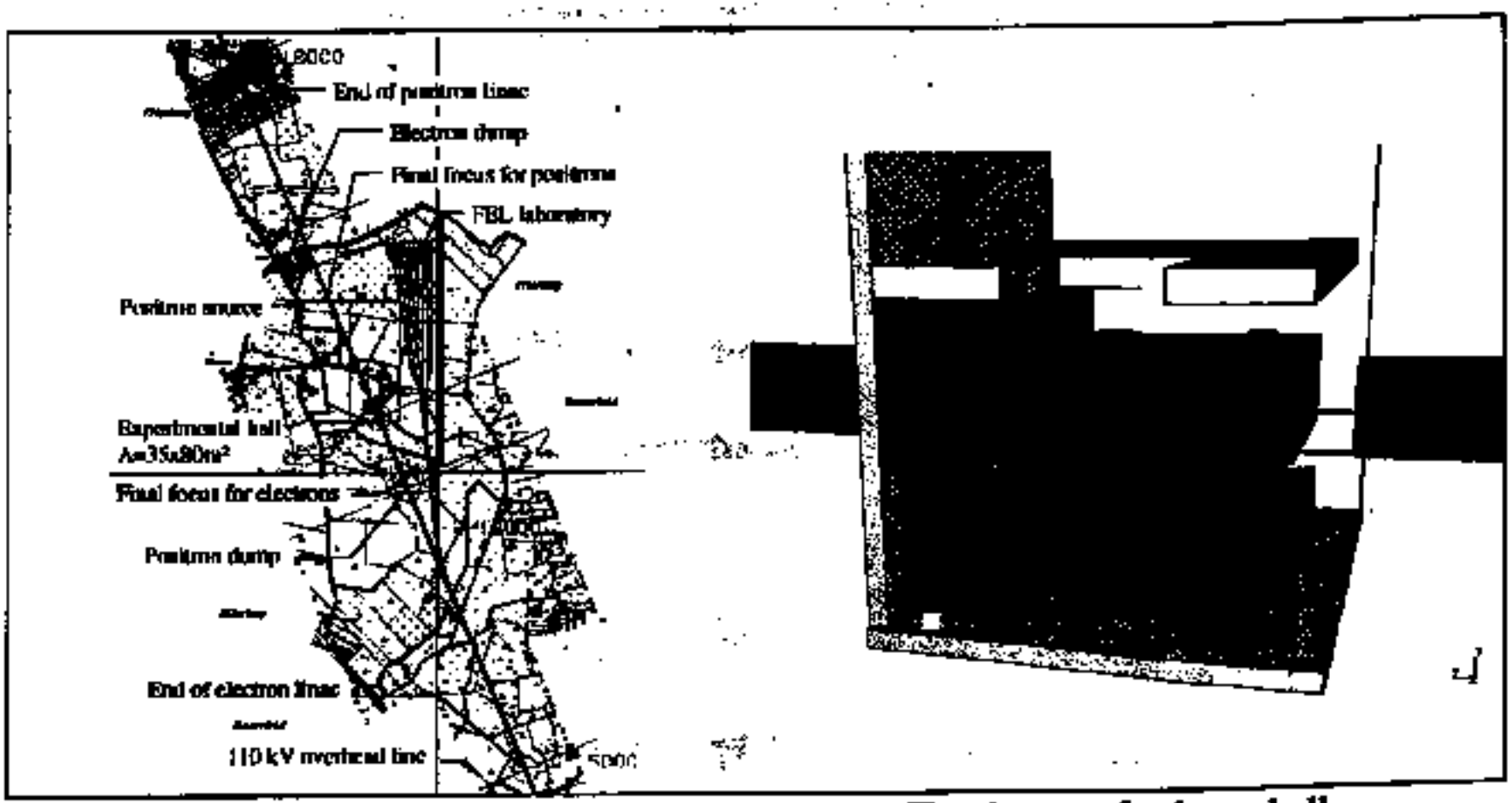
# TESLA Linac Tunnel Layout





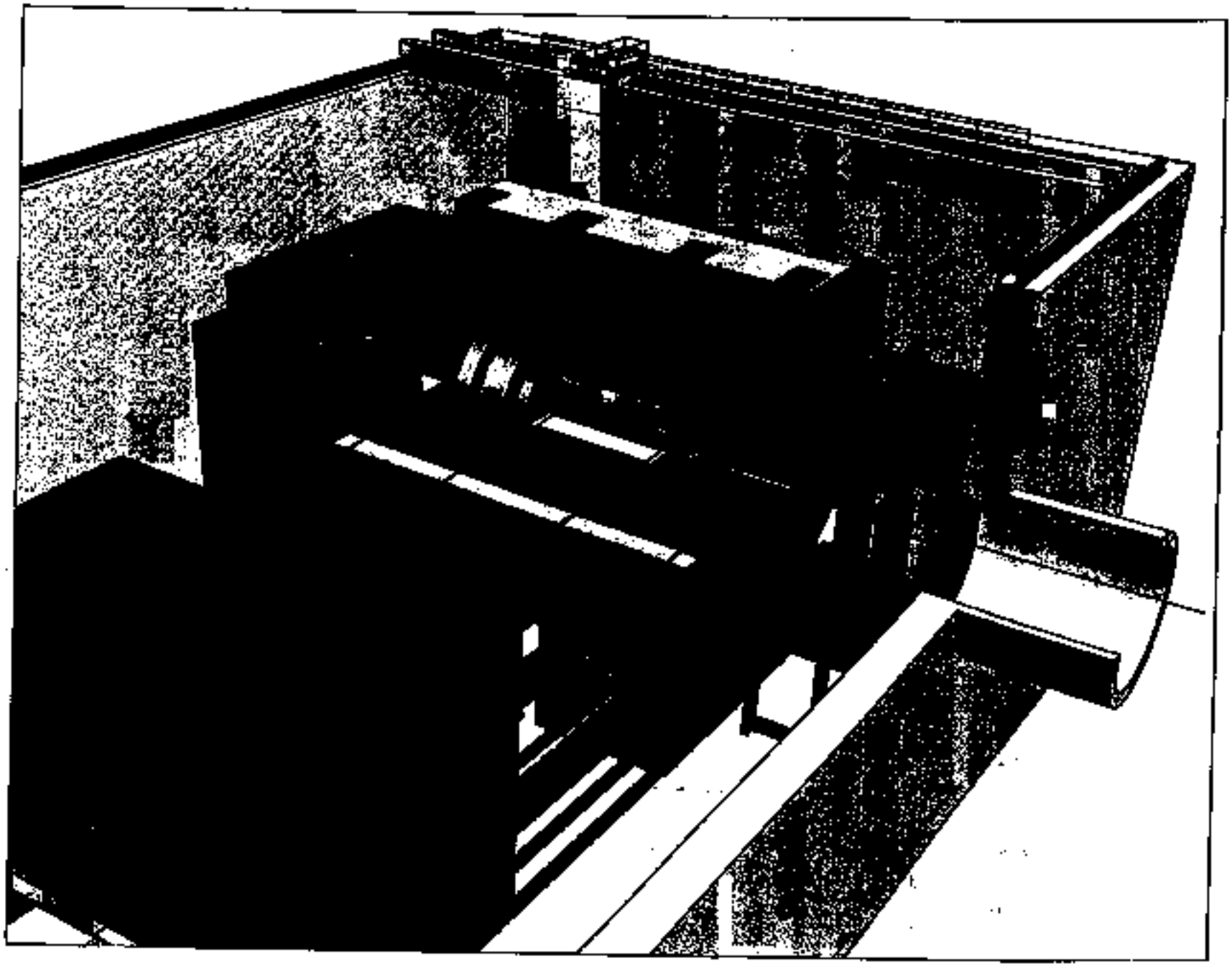
# Linear Collider

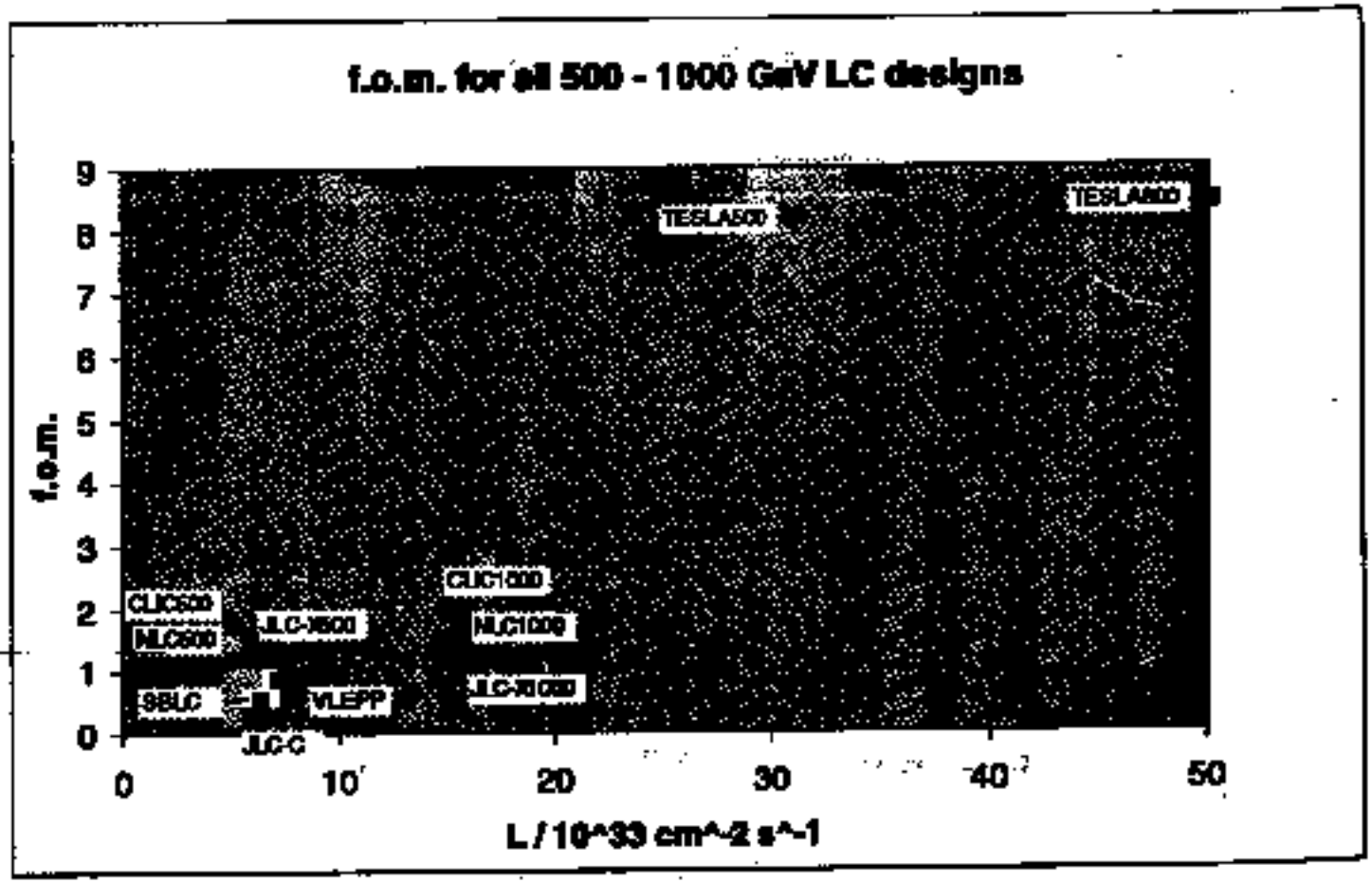





Experimental area in the center of the LC.

First layout of a dump hall.






def. of f.o.m.: $\eta/(\delta_B \cdot \varepsilon_y)^{1/2}$ (similar to definition used by J.P. Delahaye et al.)