Future Prospects for Electron Colliders

ICHEP2000 (Osaka)
Parallel Session (PA-13)

Nobu Toge (KEK)

Task assigned to this speaker is -

to give a talk encompassing both

- the status of current development on electron linear colliders (LC) and
- some description of technological developments relevant to the longer term future

Specifically, the speaker will present the following -

1. Introduction
2. Review of R&D work for near-future LCs: Tesla, NLC, JLC, CLIC
3. 90 GHz studies
4. Additional Remarks
5. Conclusions

Special thanks to -

S.Holmes, I.Wilson, R.Brinkmann, R.Siemann, H. Henke, colleagues from KEK, SLAC and FNAL.

1. Introduction

- Everyone knows that the size of e+e- storage rings L(ring) has to grow as:

  $$L(ring) \sim E_{CM}^2$$

  towards higher E_{CM}, for compensating increased amount of synchrotron radiation energy loss.
  On the other hand, in case of linear colliders (LC):

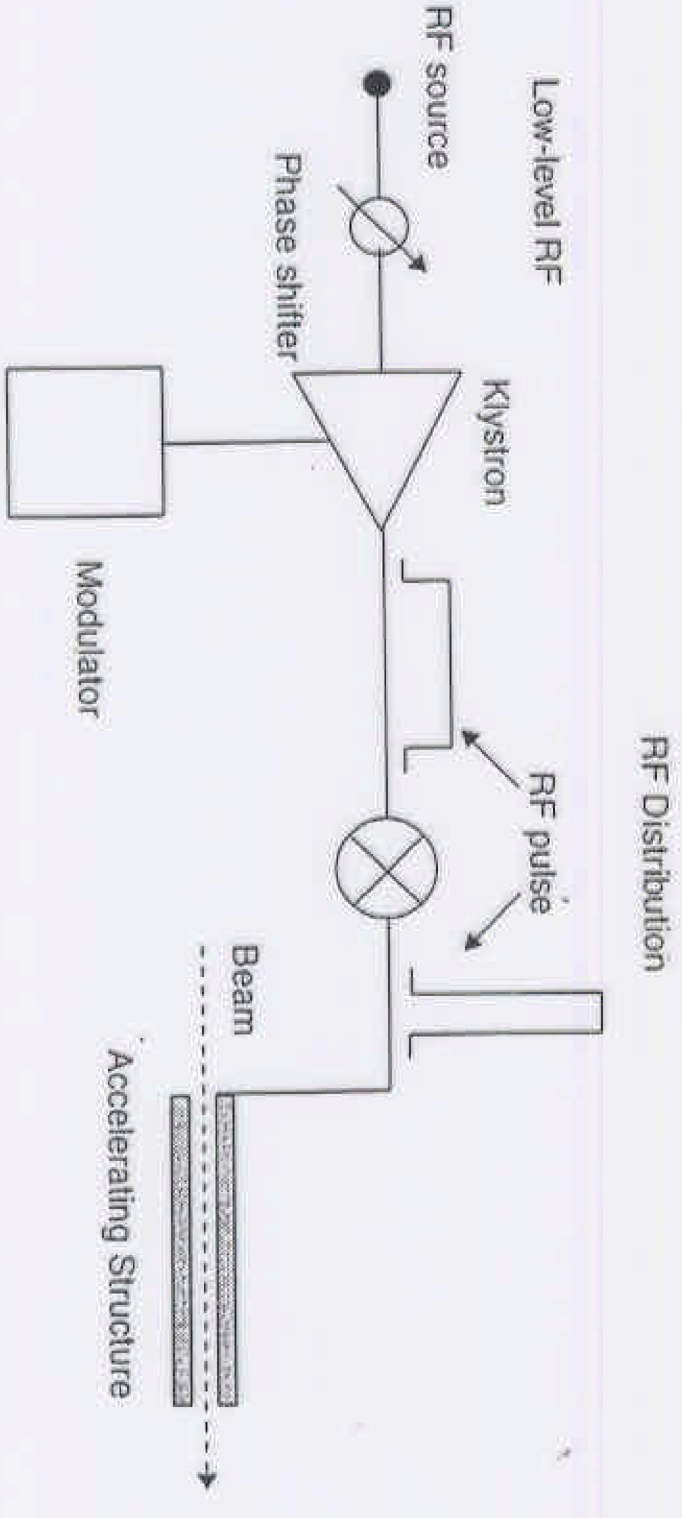
  $$L(LC) \sim E_{CM}$$

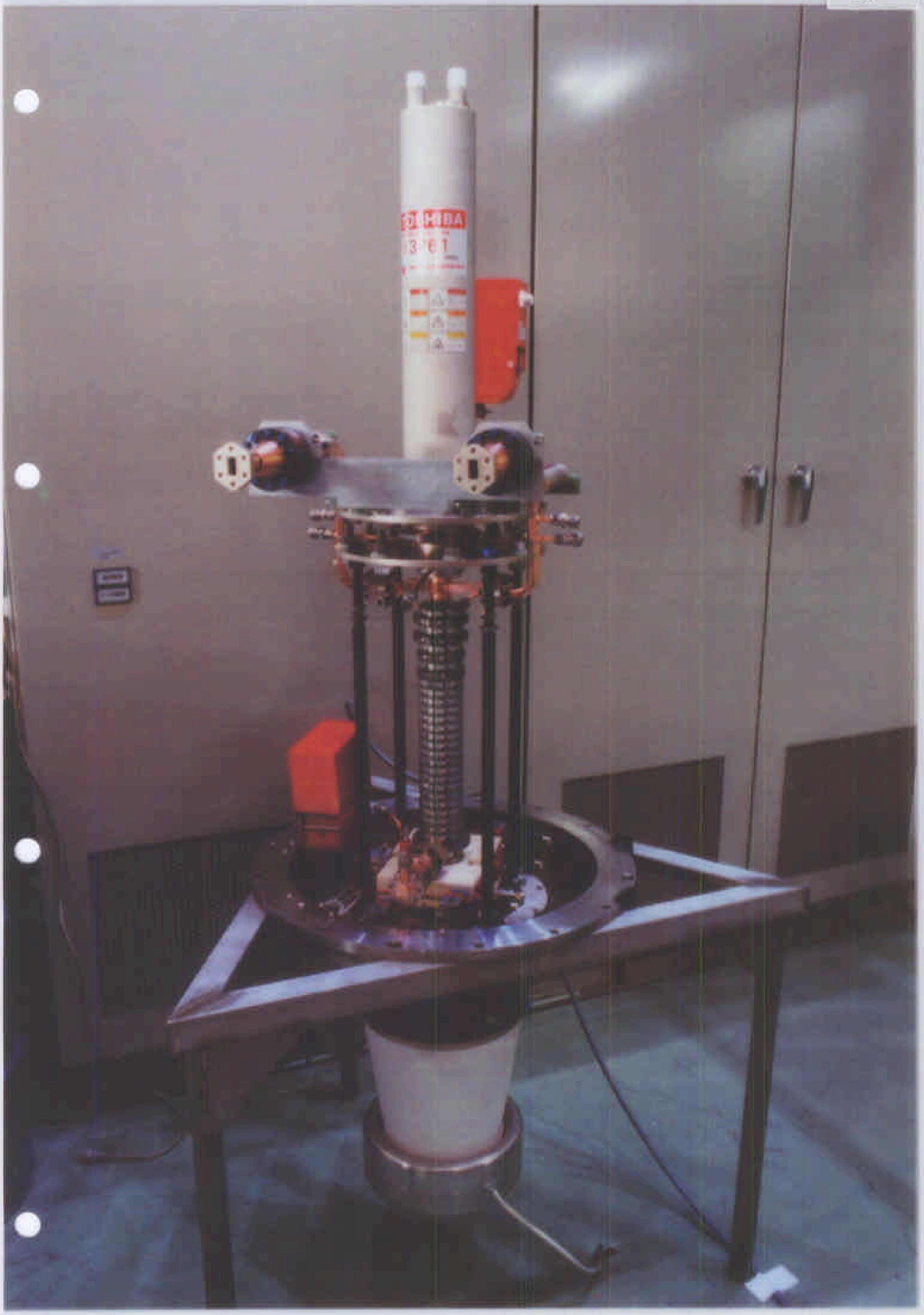
  Hence, at some point, LC should become economically a more viable HE solution. In fact, it looks like post-LEP e+e- machines already had better be an LC

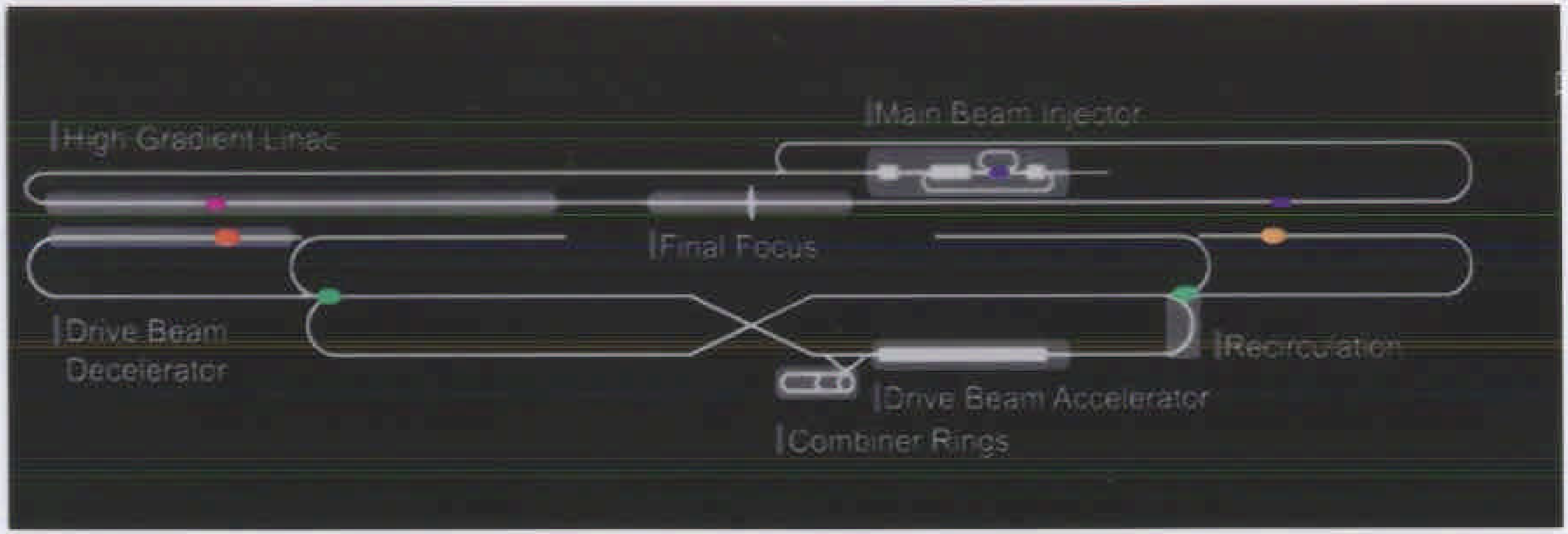
Circumference(LEP)	=	approx 30 km
Site length (500 GeV LC)	=	approx 20 km

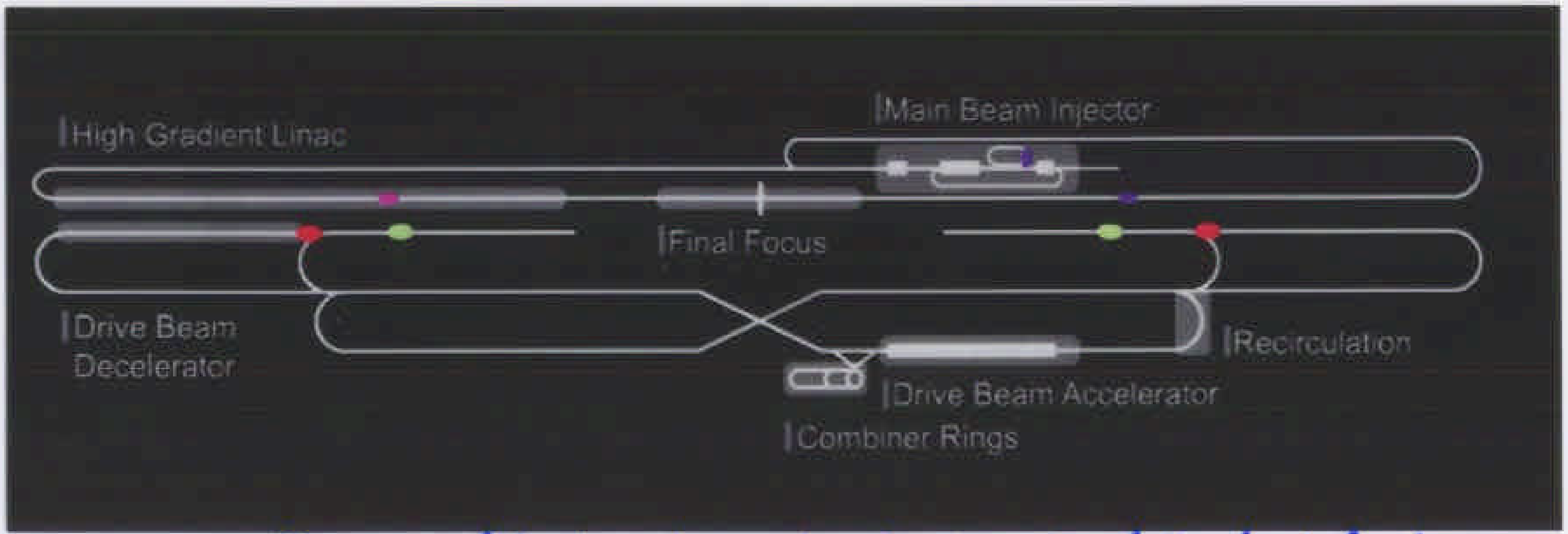
- Linac is a device that converts AC wall-plug power into kinetic energies of the beam particles that are to be accelerated.

  Accelerating structures / cavities with 50 ~ 60 Hz resonant frequencies are not too attractive, so we go to high RF.


Low-level RF
RF source
Phase shifter
Klystron
Modulator
RF Distribution
RF pulse
Beam
Accelerating Structure







http://www-sldnt.slac.stanford.edu/sld/tblc/

- High-power RF for use at a linac is created via an interaction of high-current electron beam with surrounding cavities -

  Klystron - a vacuum tube which conceptually resembles a triode.

  Working models exist for RF of a few hundred MHz up to 10 - 20 GHz.

  Two-beam Accelerator - Pick-up the power from the "drive beam" accelerator and feed it into the "colliding beam" accelerator.

  Considered an attractive option for ~ 20 GHz or above.

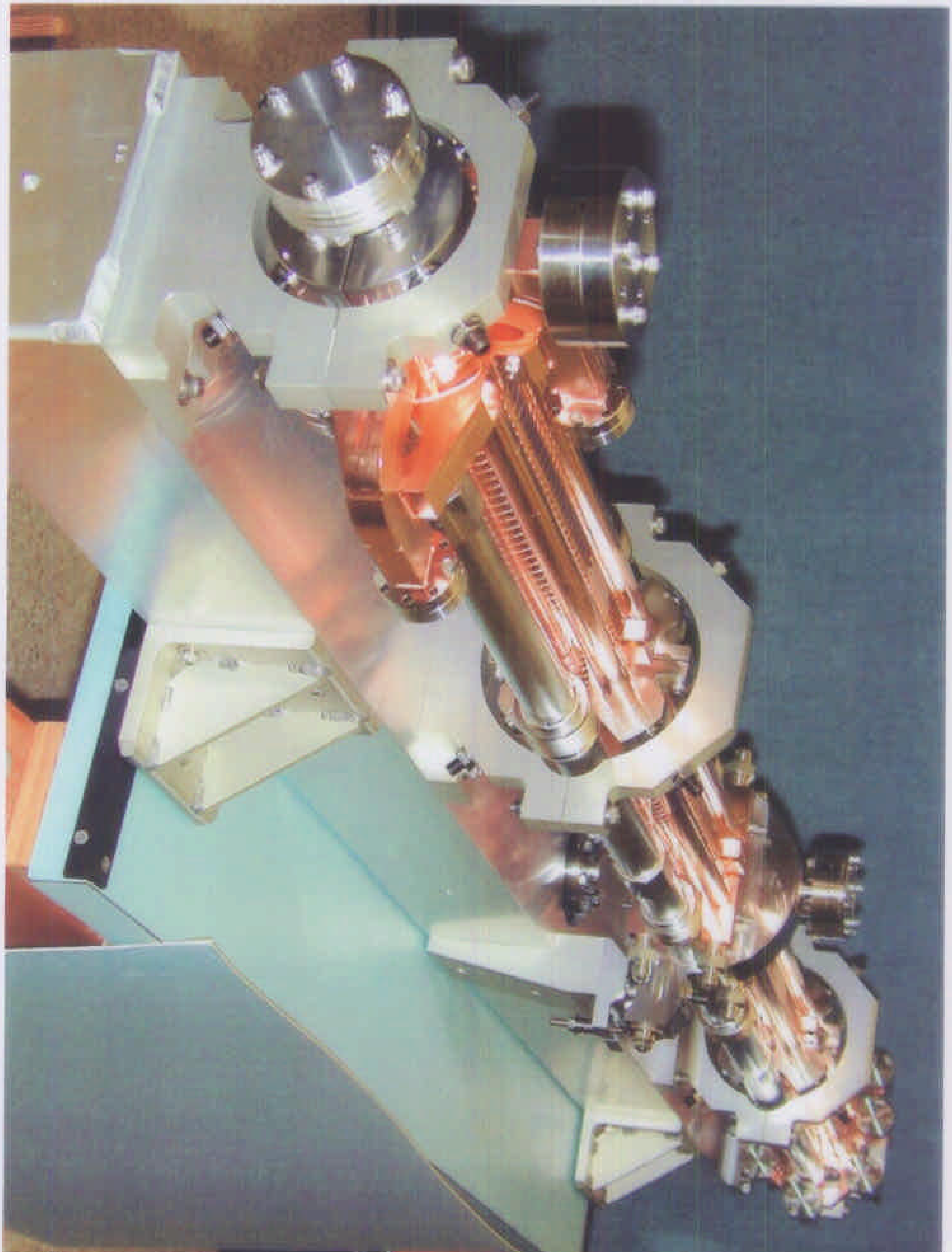
- Beam acceleration takes place in "accelerating structures", which are basically a series of resonant cavities. The frequency and phase of resonant RF are arranged, so as to precisely match the travel of accelerated beam.

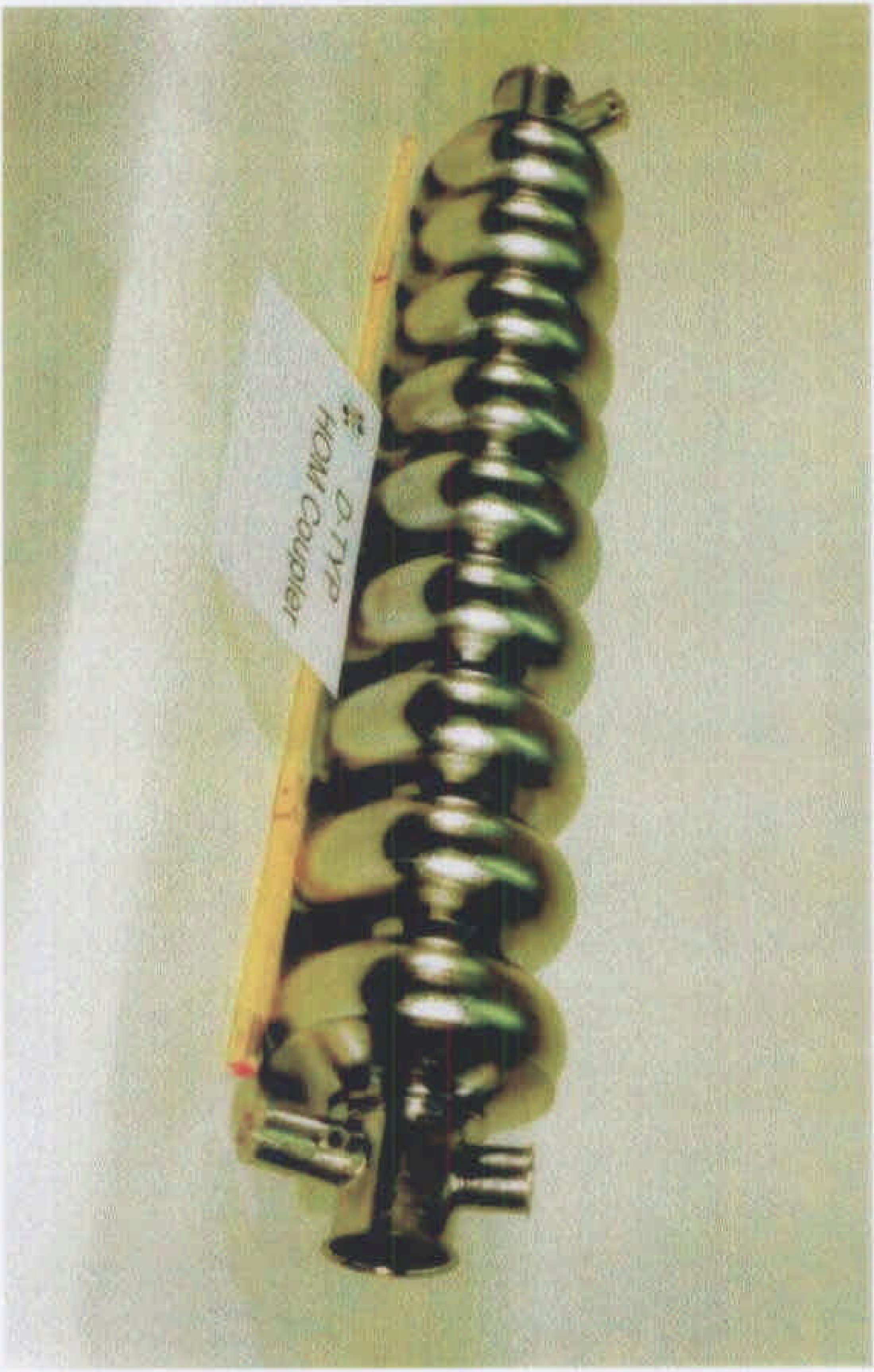
  Room-temperature copper structures - Conventional or diamond-turning machining. Higher freq RF choice is considered preferrable for improved power efficiency and robustness against discharges (at the expense of more challenging fab + assembly tolerance).

  Use at: a few up to 30 GHz or more.

  Superconducting structures - Special material and careful shaping + assembly process. Considered attractive for good power efficiency.

  Use at: Below ~ 1 GHz.

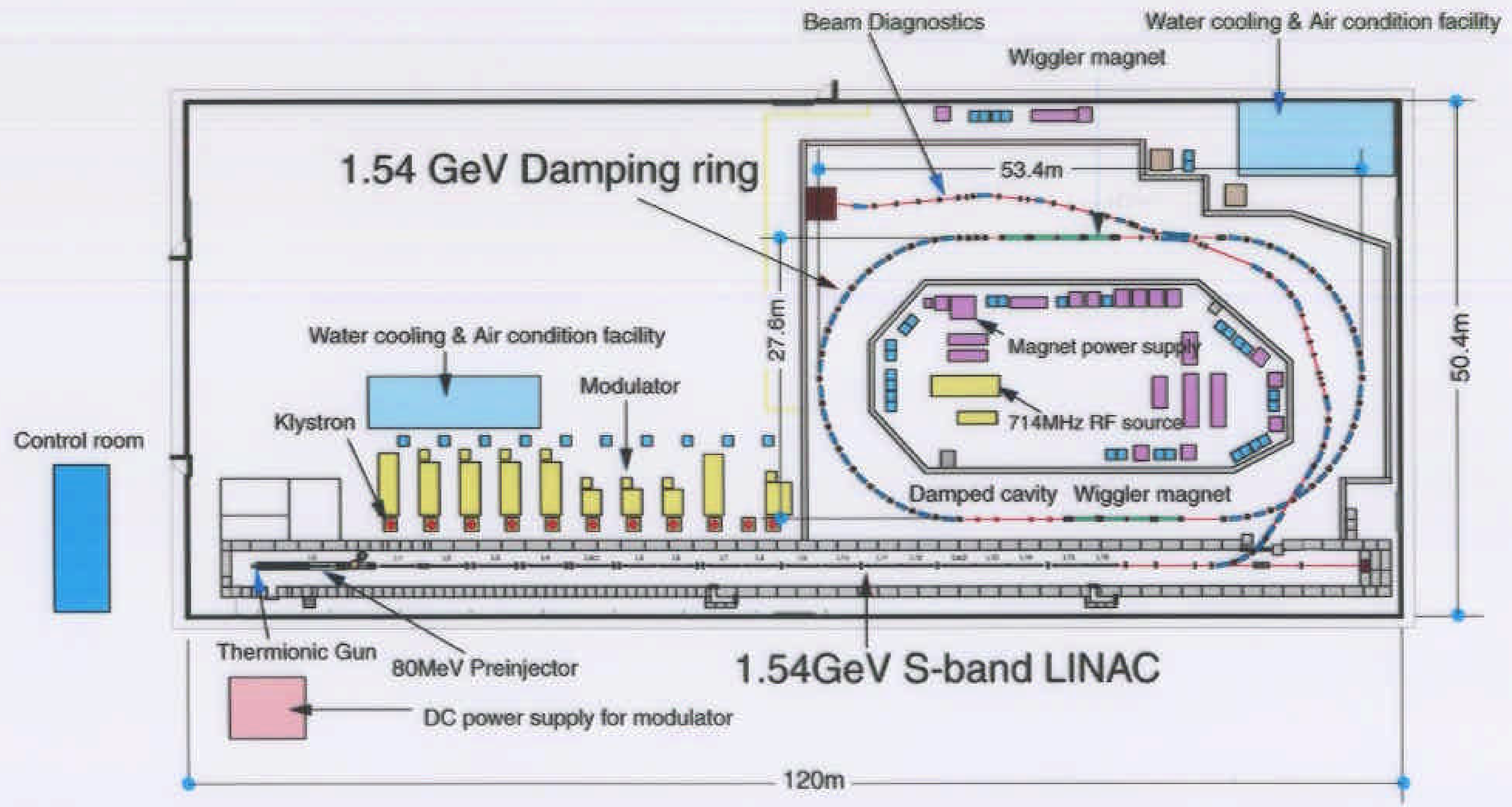



D-TYP
HOM Coupler

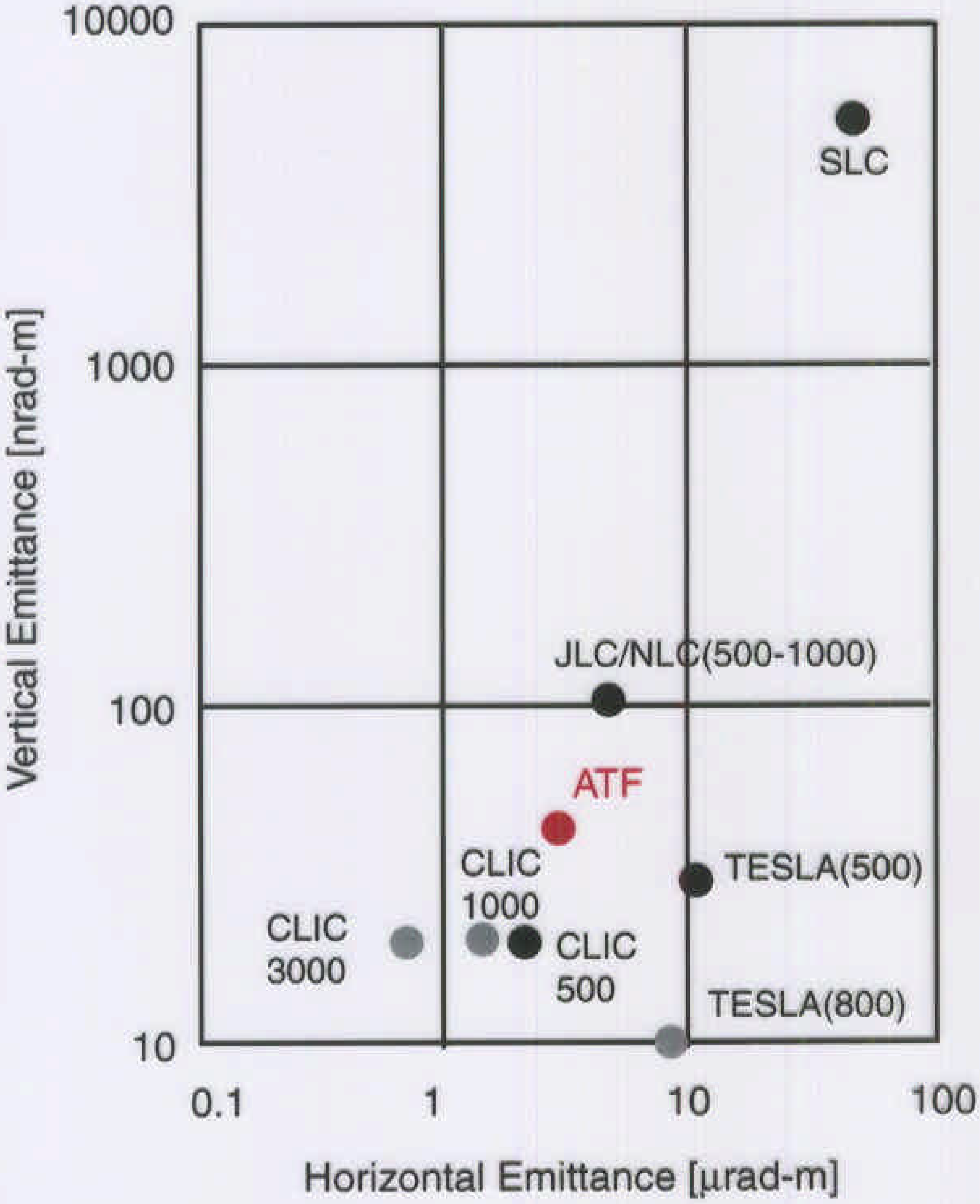
ATF AT KEK.

$\epsilon_x = 1.4 \times 10^{-9}$ m.rad
$\epsilon_y = (2-3) \times 10^{-11}$

$\gamma \to 2400$



Normalized beam emittances in Linear Colliders



ATF at KEK has basically demonstrated the feasibility of producing ultra-low emittance beams, although it has remaining issues to address in higher intensity, multi-bunch beam operation in coming years.

Luminosity Formula

$$\mathcal{L} = f_{REP} \frac{N_B \, N^+ \, N^-}{4\pi \, \sigma_x \, \sigma_y} H_D$$

$$\propto \frac{P_{AC} \, \eta_{AC \to RF} \, \eta_{RF \to BEAM}}{E_{CM}} \sqrt{\frac{\delta_B}{\epsilon_y}} H_D$$

(Keep $\delta_B \sim 2-4\%$)

$H_D \sim 1.8$ Typically

http://www.slac.stanford.edu/xorg/ilc-trc/ilc-trchome.html (Case: ECM = 500 GeV)

	TESLA	JLC(C)	JLC/NLC(X)	CLIC
Accelerator	S.C.	N.C.	N.C.	N.C. /2-beam
RF freq [GHz]	1.3	5.7	11.4	30
Eacc [MV/m]	22	34	55	150
N(elec) / Bunch [10^{10}]	2	1.11	0.95	0.4
N(bunch) / Beam	2820	72	95	154
Bunch spacing [ns]	337	2.8	2.8	0.67
Bunch train length	950 μs	202 ns	270 ns	103 ns
Beam Emittance [10^{-6} m]	10 / 0.03	3.3 / 0.05	4.5 / 0.1	2 / 0.02
x / y beam size at IP [nm]	553 / 5	318 / 4.3	330 / 4.9	202 / 2.5
z beam size [mm]	0.4	0.2	0.12	0.03
Two-linac length [km]	30	16	10.5	4.6
AC power to make RF [MW]	95	130	100	100

SLC had been running an S-band linac (2.9 GHz) at ~ 17 MV/m.

Introduction (Continued)

A few remarks -

- All require multi-bunch beams with ultra-low emittance to be accelerated; so some kind of damping rings is a must.
- All require bunch lengths much shorter than 1 mm to be accelerated in main linacs, because of the very small $\beta_y{}^*$ at IP. Thus, some kind of bunch length compression or a bunch source with short bunch length is a must.
- The required scale of the infrastructure for supporting an LC facility is roughly comparable to that of LEP (or maybe somewhat bigger). It is not too crazy.
- However, the precision that is required in construction + operation of the complex RF systems (beam control systems, also) is far more substantial than any existing accelerator facilities. It may appear crazy to some.
- Despite major technical challenges, the R&D teams worldwide have been making steady progress. No fundamental impossibility of an LC with E_{CM} = 500 - 1000 GeV has been proven. So, we keep working.

2A. TESLA

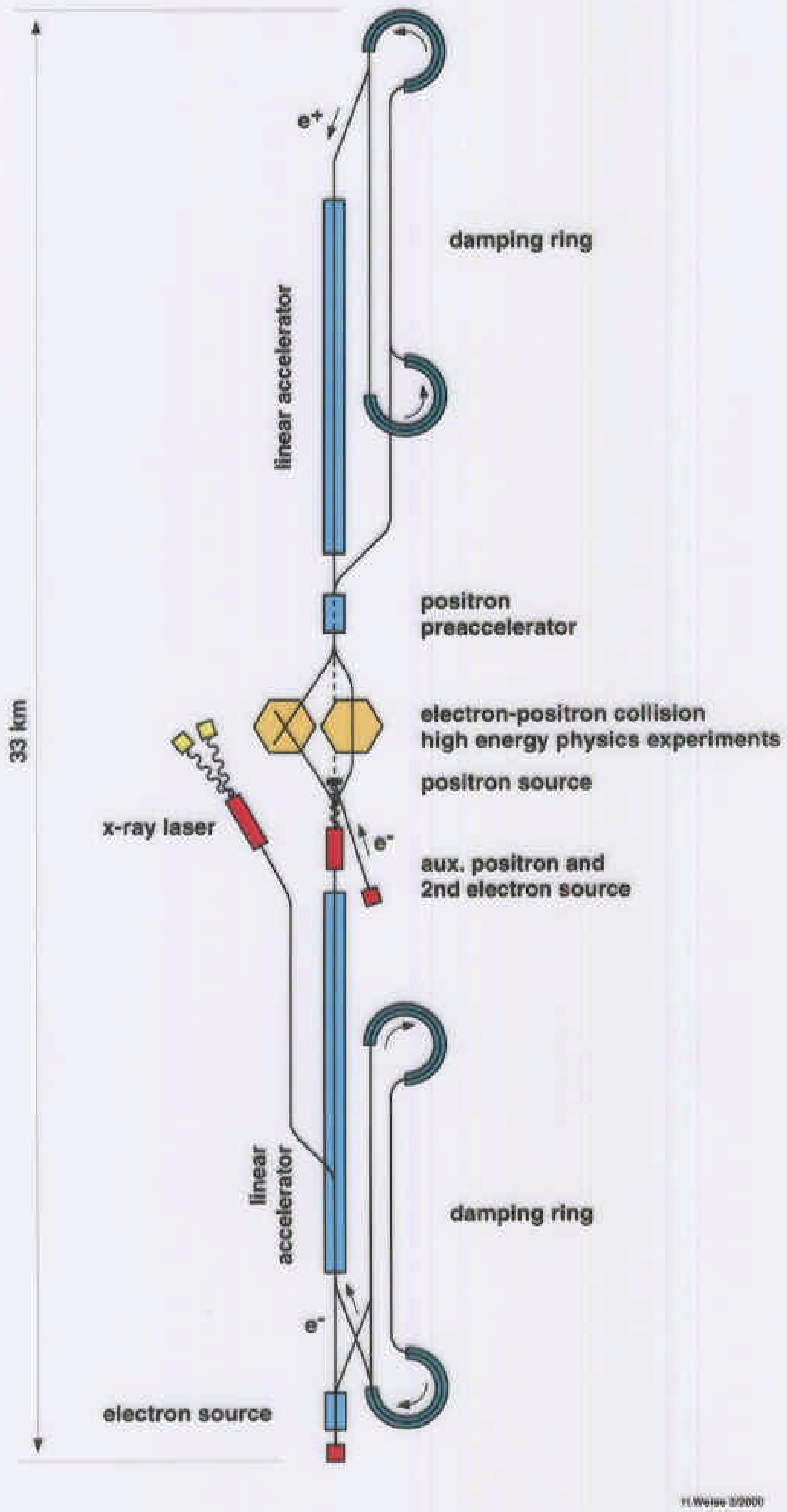
- The low RF losses on the S.C. cavity walls lead to -
  - High conversion eff of AC --> beam power
  - Long RF pulses allow many bunches spaced wide apart, which means

    Head-on collision possible
    Fast bunch-to-bunch orbit feedback.

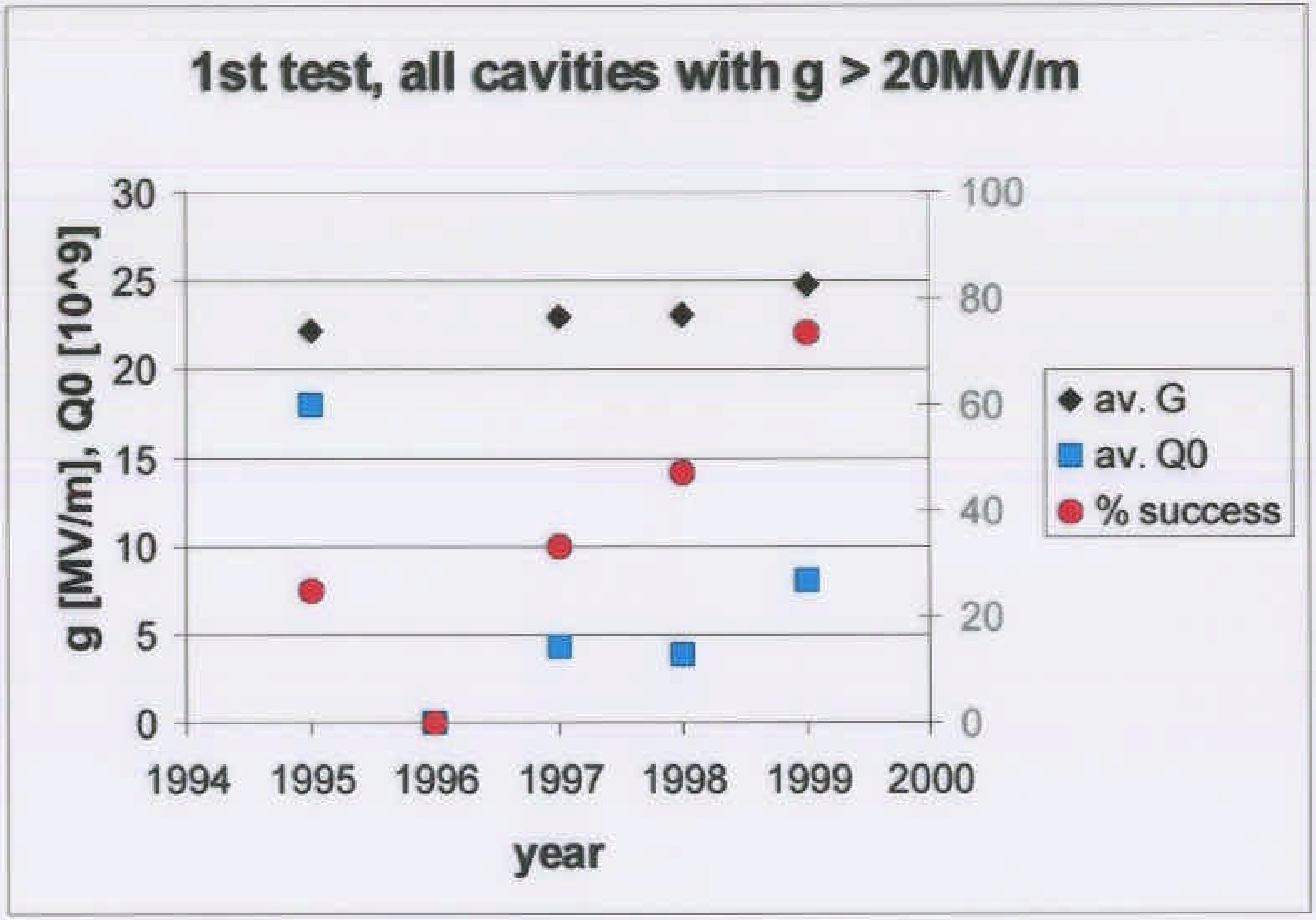
- SC choice favors lower RF freq for increased shunt impedance (quite contrary to NC cases), so picked up 1.3 GHz.
  - As an advantage transverse wake is also reduced at lower RF freq.

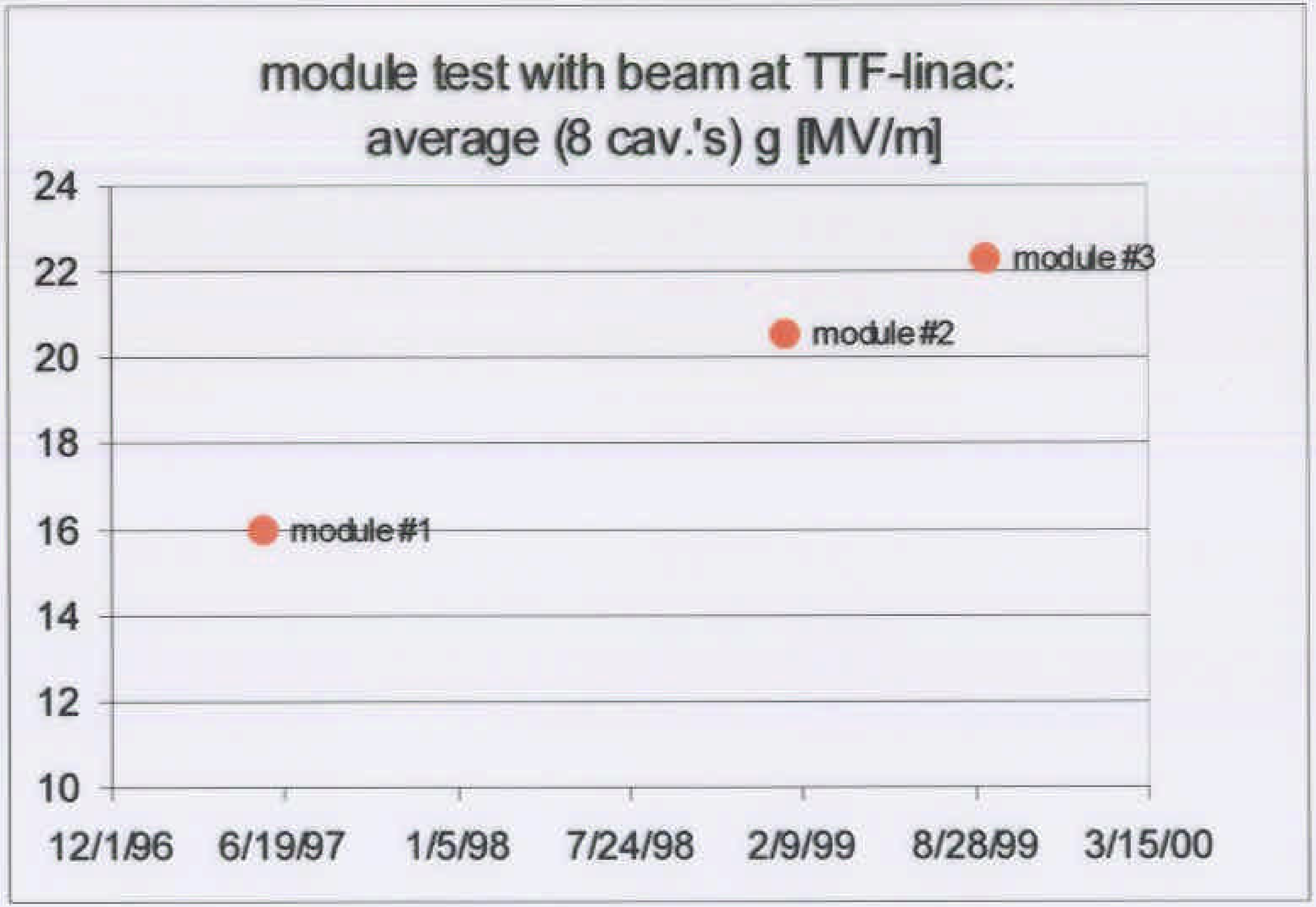
- SC cavity R&D
  - Steady progress in achieved Eacc (majority > 15 MV/m, many > 20 MV/m) vs Q (3 - 10E10) in 9-cell cavities.
  - "Superstructure" concept (4 x 7-cell cavities fed by a single coupler, rather than 3 x 9 fed by three couplers) for reduced cavity-cavity spacing (better packing factor) and reduced number of coupler components.

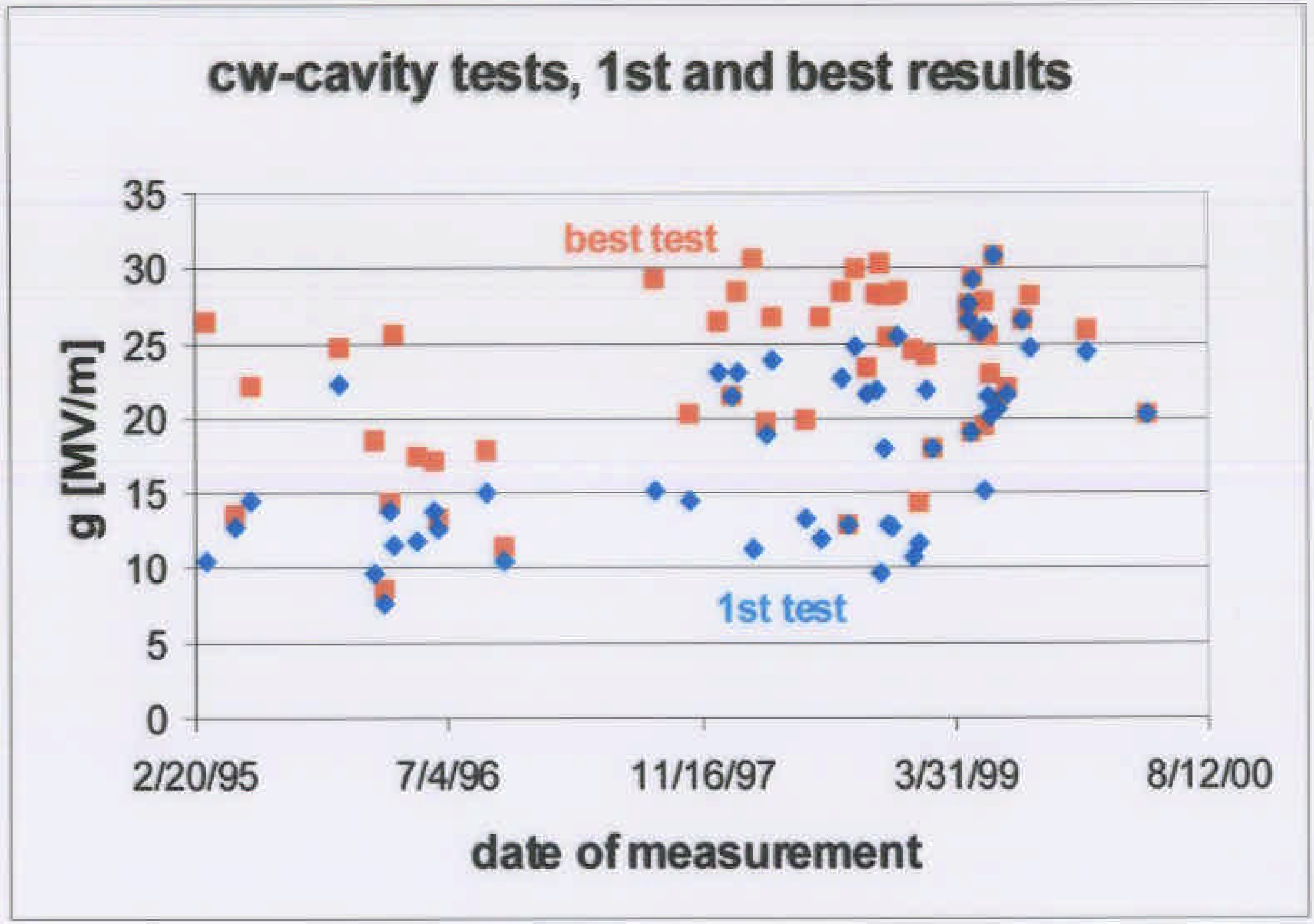
	TESLA-500	TESLA-800
acc. gradient [MV/m]	22	35
AC power [MW]	100	160
t_{pulse} [μs]	950	860
# bunches n_b/pulse	2820	3570
bunch spacing Δt_b [ns]	337	241
rep. rate f_{rep} [Hz]	5	4
N_e/bunch [10^{10}]	2	1.4
$\varepsilon_x / \varepsilon_y$ (@ IP) [10^{-6}m]	10 / 0.03	8 / 0.015
beta at IP $\beta_{x/y}^*$ [mm]	15 / 0.4	15 / 0.3
spot size σ_x^* / σ_y^* [nm]	553 / 5	391 / 2.4
bunch length σ_z [mm]	0.3	0.3
beamstrahlung δ_B [%]	3.3	4.7
Disruption D_y	25	32
lumin. L [10^{34} cm^{-2}s^{-1}]	3.4	4.2



e+
damping ring
linear accelerator
positron
preaccelerator
electron-positron collision
high energy physics experiments
33 km
positron source
x-ray laser
e-
aux. positron and
2nd electron source
linear
accelerator
damping ring
e-
electron source
H.Weise 3/2000


1st test, all cavities with g > 20MV/m
g [MV/m], Q0 [10^9]
0
5
10
15
20
25
30
0
20
40
60
80
100
1994
1995
1996
1997
1998
1999
2000
year
av. G
av. Q0
% success


module test with beam at TTF-linac:
average (8 cav.'s) g [MV/m]
24
22
20
18
16
14
12
10
12/1/96
6/19/97
1/5/98
7/24/98
2/9/99
8/28/99
3/15/00
module #1
module #2
module #3


cw-cavity tests, 1st and best results
g [MV/m]
35
30
25
20
15
10
5
0
best test
1st test
2/20/95
7/4/96
11/16/97
3/31/99
8/12/00
date of measurement

2B. JLC C-band Option

C-band = 5.6 GHz.
Eacc ~ 40 MV/m

Fast-track R&D has been possible thanks to relatively straightforward (if not trivial) extrapolation from the S-band technology, plus hard work.

Modulator :

350 kV, 2.6 μs, Eff = 52.4 % achieved
New model with Eff > 60 % in design

Klystron:

Solenoid focussing type:
50 MW, 2.5 μs, 50 Hz, 3 tubes so far.
#2 model running > 3000 hrs.
All successful.

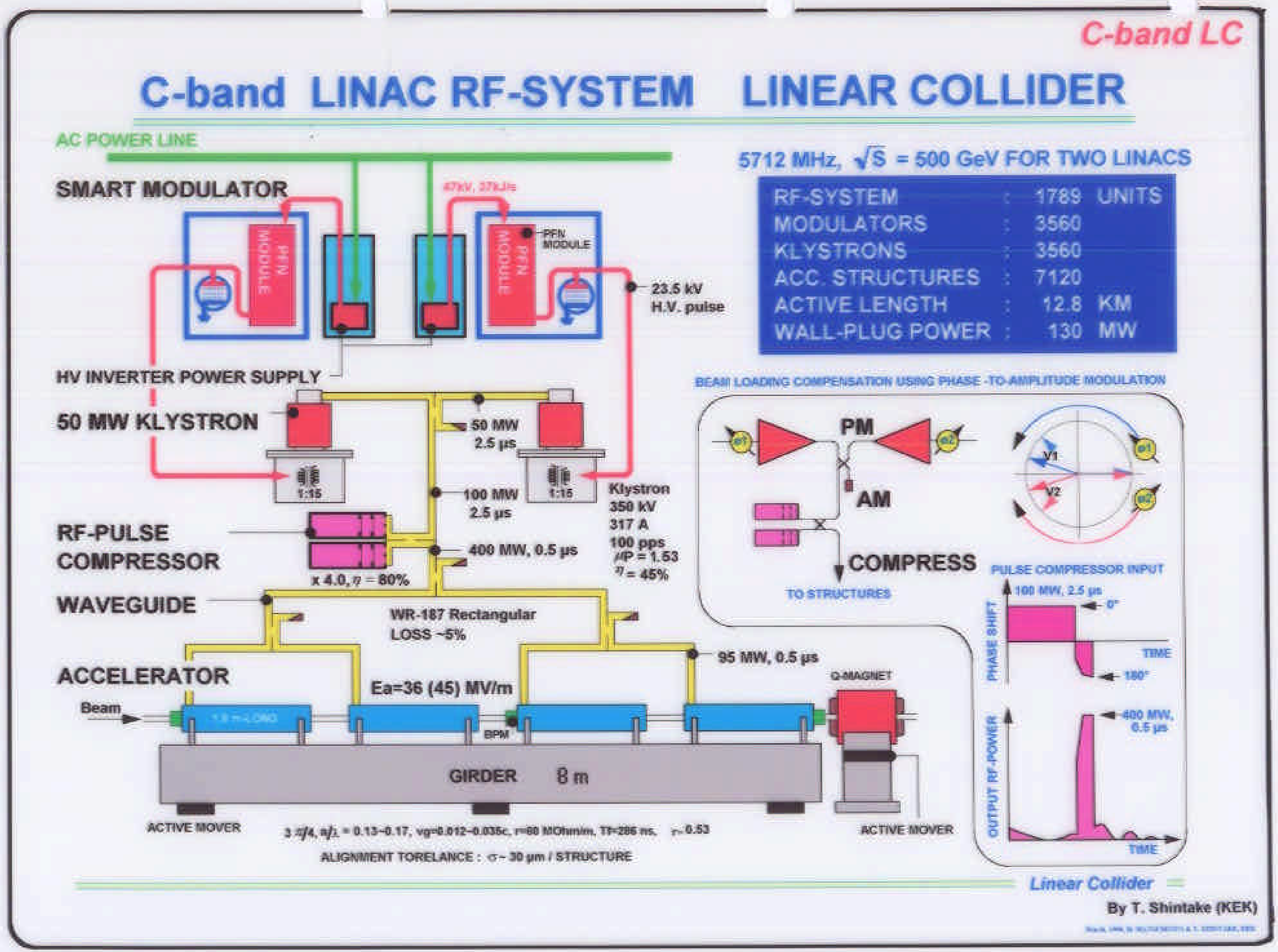
PPM focussing type:
First model built in 1999 - 2000.
Test to start in July 2000.

RF Pulse Compression:

Disk-loaded SLED (SLED-III)
Gain = 3.25, Eff = 65 % in cold-model.
High-power testing under planning.

Accelerating Structure:

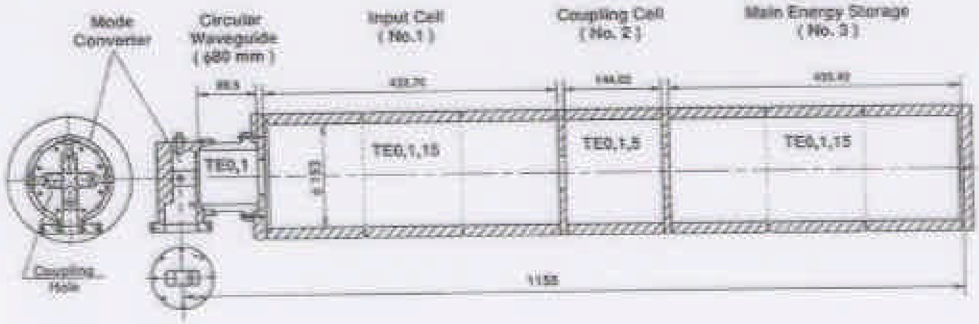
Choke-mode-type for superior HOM suppression.
Encouraging result at SLAC ASSET testing.
High-power testing required.


C-band LC
C-band LINAC RF-SYSTEM LINEAR COLLIDER
AC POWER LINE
SMART MODULATOR
47kV, 37kJ/s
PFN MODULE
PFN MODULE
23.5 kV
H.V. pulse
HV INVERTER POWER SUPPLY
50 MW KLYSTRON
50 MW
2.5 μs
1:15
1:15
100 MW
2.5 μs
Klystron
350 kV
317 A
100 pps
μP = 1.53
η = 45%
RF-PULSE
COMPRESSOR
400 MW, 0.5 μs
x 4.0, η = 80%
WAVEGUIDE
WR-187 Rectangular
LOSS ~5%
95 MW, 0.5 μs
ACCELERATOR
Ea=36 (45) MV/m
Beam
BPM
Q-MAGNET
GIRDER 8 m
ACTIVE MOVER
ACTIVE MOVER
ALIGNMENT TORELANCE : σ~ 30 μm / STRUCTURE
5712 MHz, √S = 500 GeV FOR TWO LINACS
RF-SYSTEM : 1789 UNITS
MODULATORS : 3560
KLYSTRONS : 3560
ACC. STRUCTURES : 7120
ACTIVE LENGTH : 12.8 KM
WALL-PLUG POWER : 130 MW
BEAM LOADING COMPENSATION USING PHASE -TO-AMPLITUDE MODULATION
PM
AM
COMPRESS
TO STRUCTURES
V1
V2
PULSE COMPRESSOR INPUT
100 MW, 2.5 μs
0°
180°
PHASE SHIFT
TIME
OUTPUT RF-POWER
400 MW, 0.5 μs
TIME
Linear Collider
By T. Shintake (KEK)

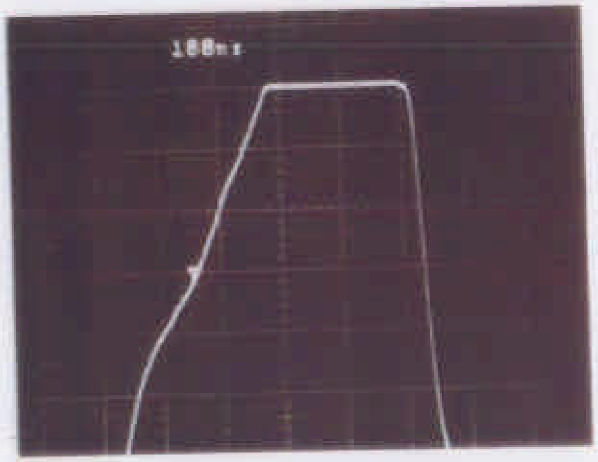
New Type RF Pulse Compressor

Cold Model Test, 1997

3-cell Compressor Cavity (1 meter long)



Compressed Pulse

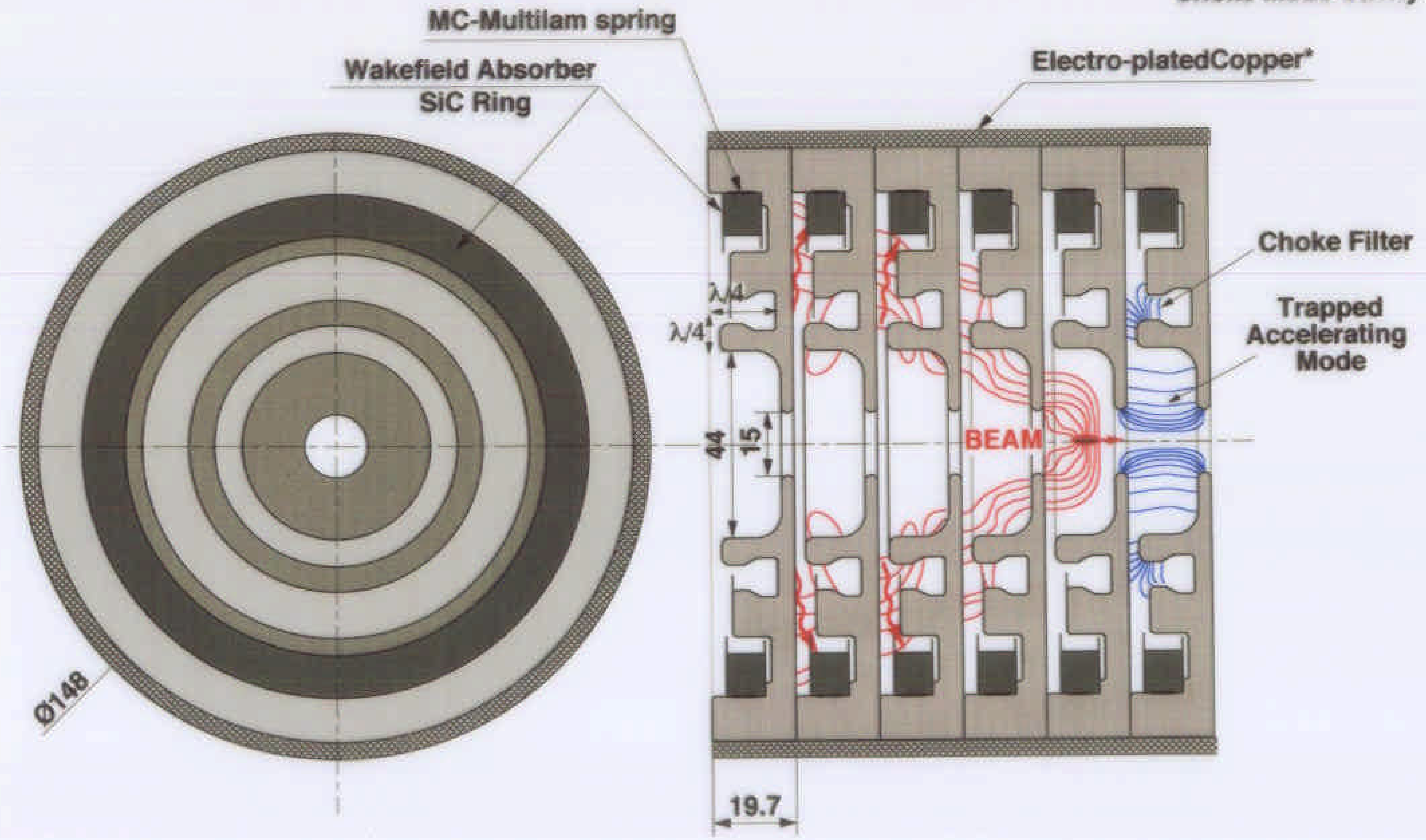


(Gain 3.4)

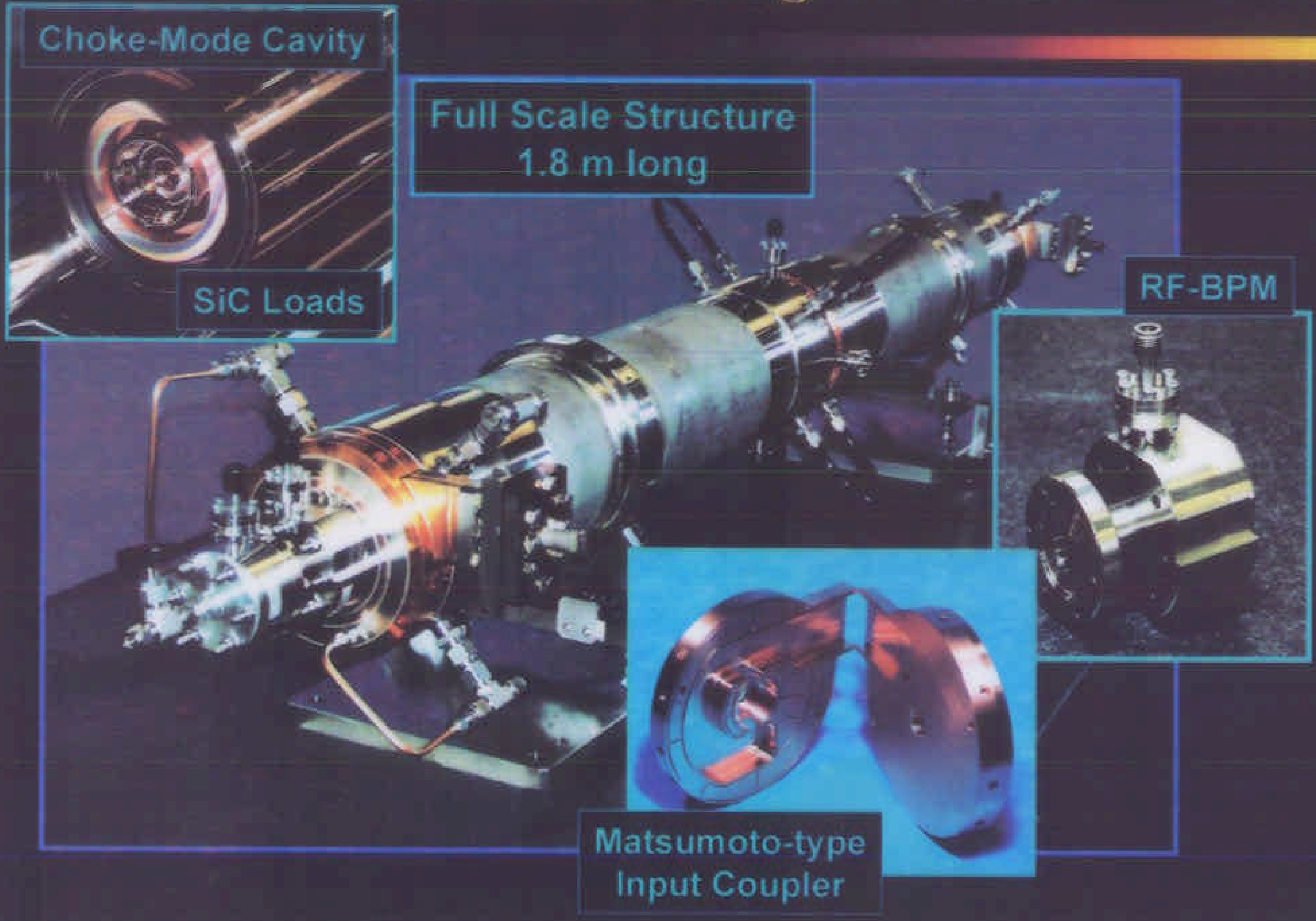
Flat top detail.

C-band HOM Free Accelerating Structure

Choke Mode Cavity

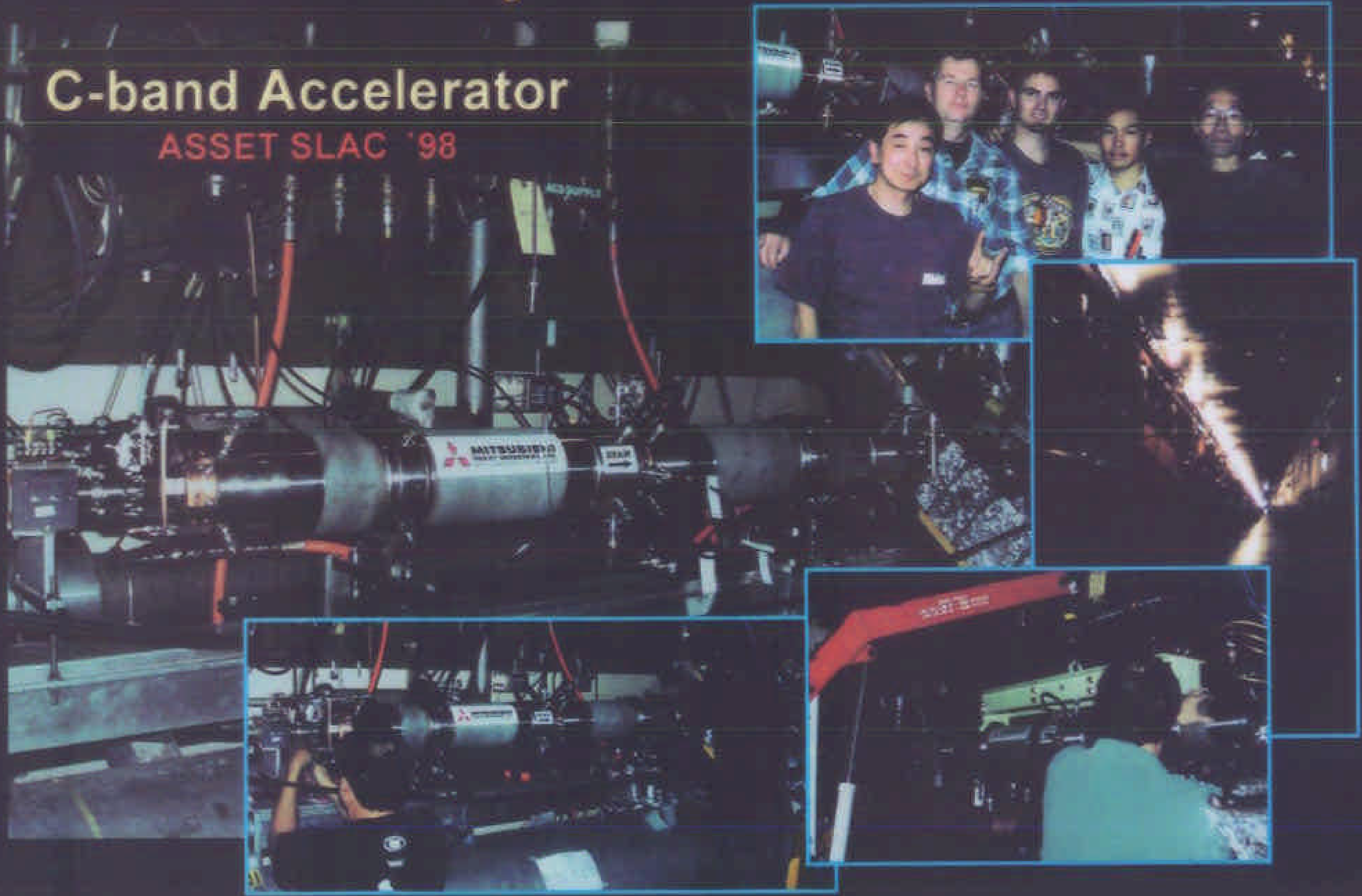


C-band Accelerating Structure

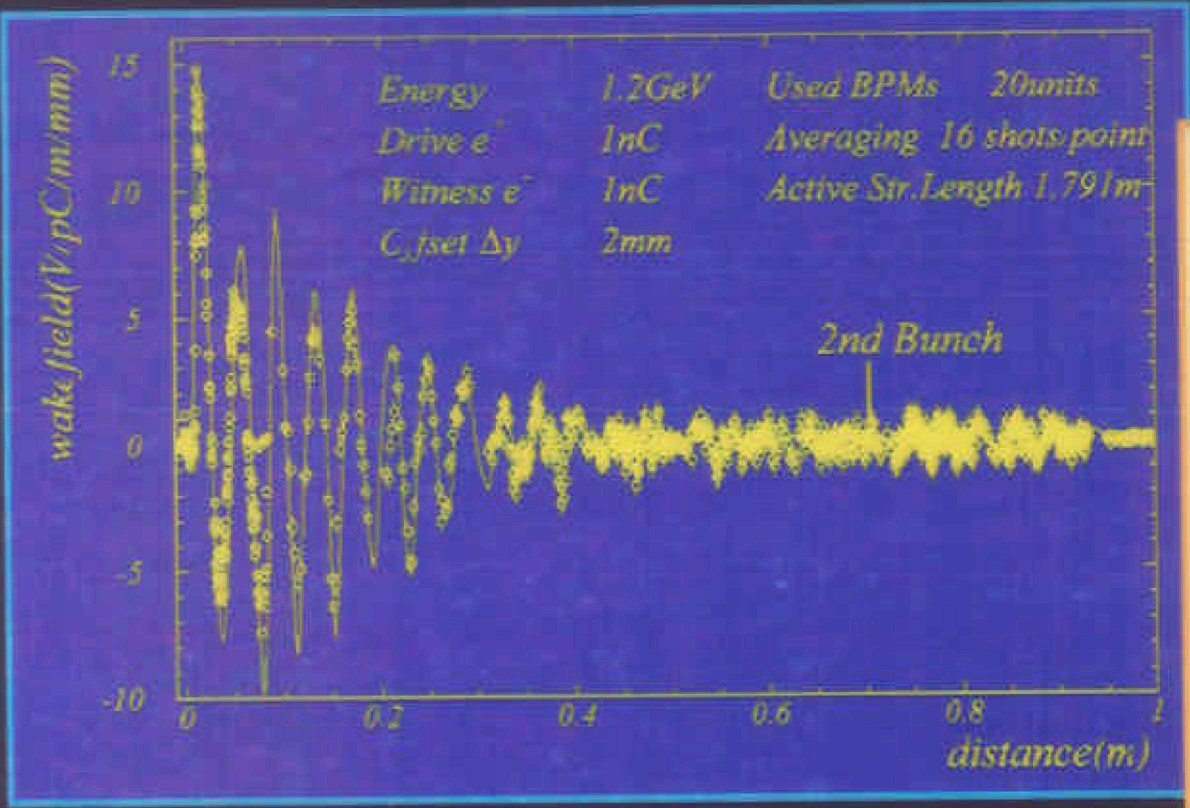


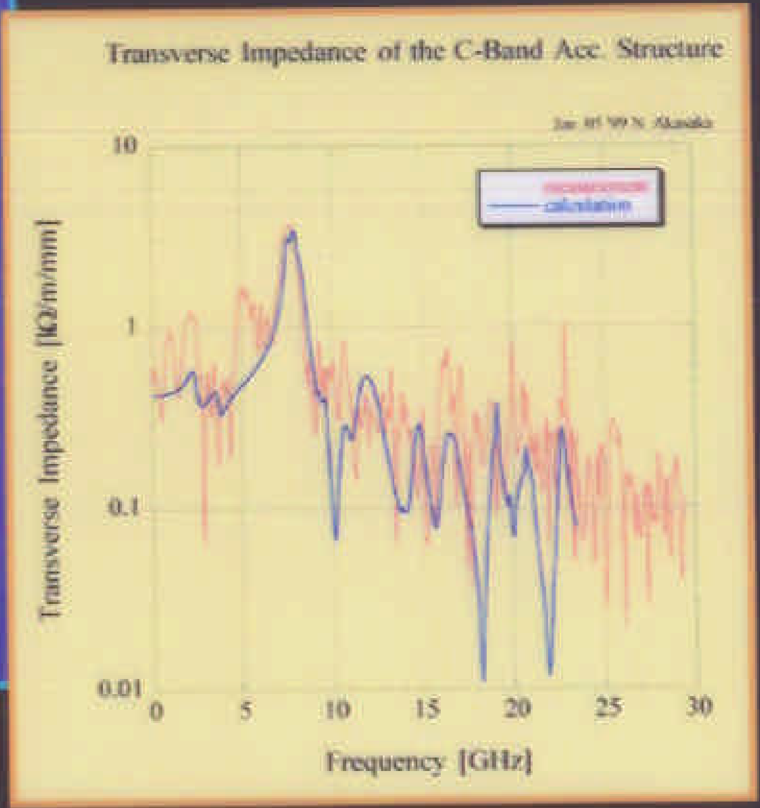
C-band R&D

Wakefield Measurement

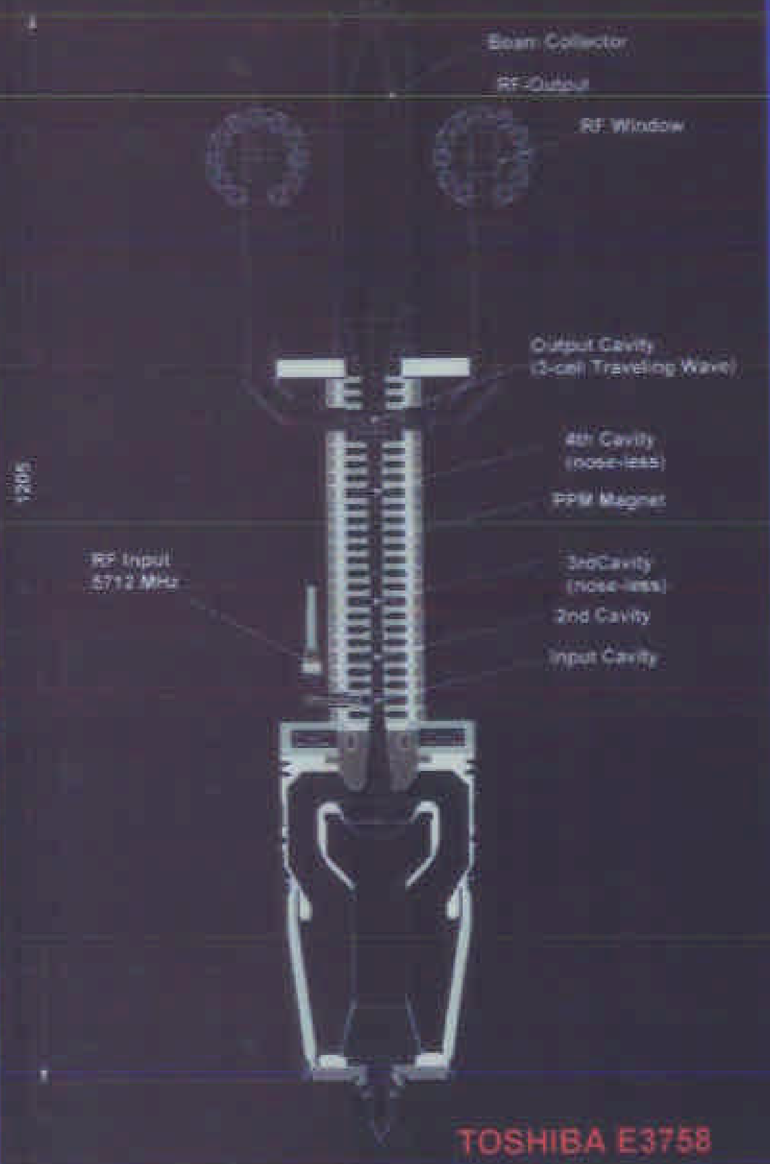


Measured Wakefield

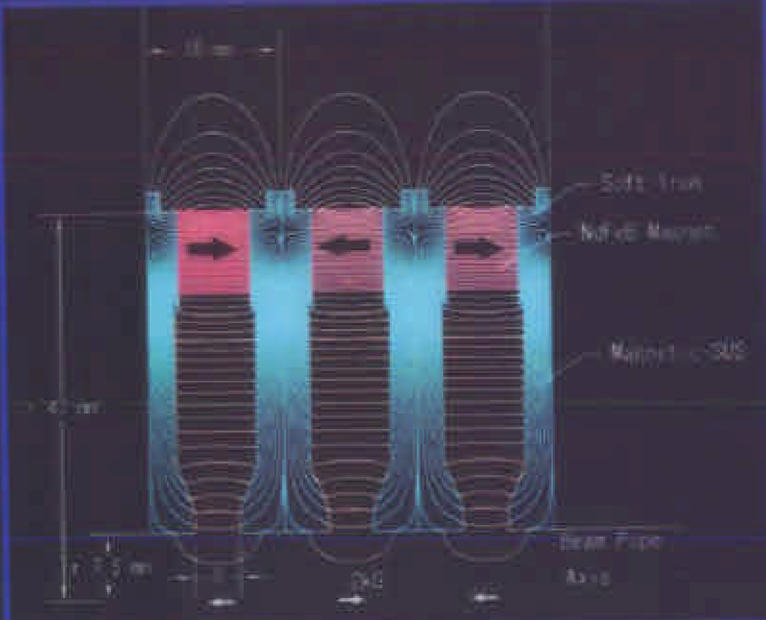




C-band PPM Klystron (1999 Model)



- Periodic Permanent Magnet Focused
- Permanent Magnet : NdFeB
- Designed parameter
  - Peak output : 50 MW
  - Efficiency : 50%
  - μ Perveance : 1.53
  - Voltage : 350 kV
  - Pulse Width 2.5 μsec



C-band Klystron Development

Accumulated operating time is 4,500 hours since April in 1998

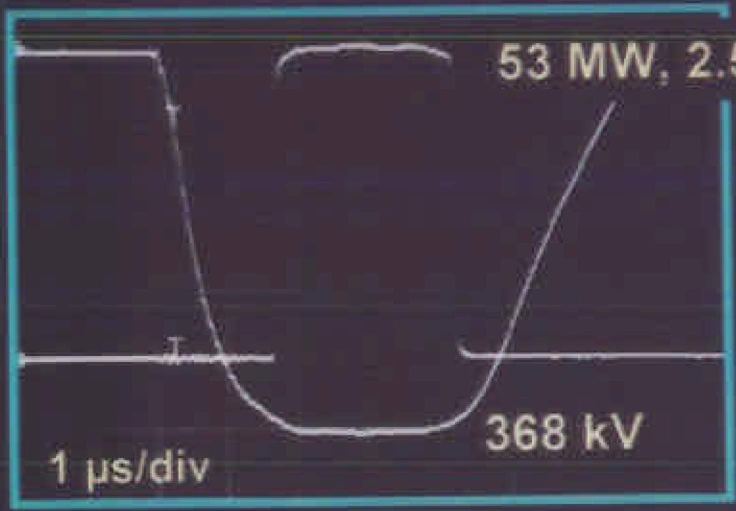
Traveling-wave output structure

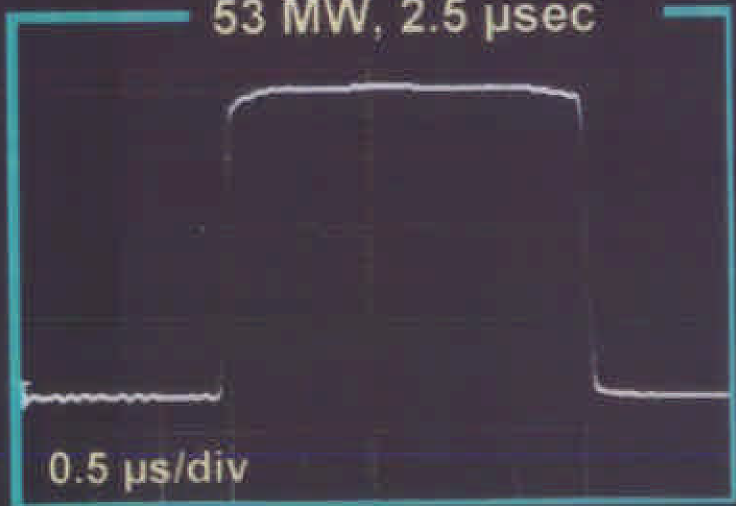
Solenoid Focus (4.6kW)

1.5 μP

Dispenser Cathode (D74.5mm,6.3A/cm²)

TOSHIBA E3746 No.2





53 MW, 2.5 μsec, 50 pps, 44%

2C. NLC / JLC X-band Option

X-band = 11.424 GHz.
Eacc ~ 55 MV/m

Ambitious extrapolation from the S-band technology.

Beam acceleration and beam-loading compensation already demonstrated (somewhat in a limited scope) in the past at NLCTA (SLAC).

NLC collaboration in US.
KEK-SLAC R&D collaboration (ISG) formalized in 1998.

Modulator :
- SLAC/KEK parallel efforts
- Study semiconductor switches "for the future".

Klystron:
- KEK/SLAC parallel efforts
- PPM focussing type:
  - 75 MW, > ~ 2μs achieved in 1999.
  - Design refinment + test assy on-going.

RF Pulse Compression:
- SLAC/KEK joint effort
- DLDS (Delay Line Distribution System)
- Superior eff.
- Numerous low-power testing gave encouraging results.

Accelerating Structure:
- KEK/SLAC joint effort
- Damped-Detuned Structure with Rounded corners (RDDS)
- Precision machining + assy technology at hand.
- Wake field meas (ASSET@SLAC) agree with calc.
- Stability issues in high Eacc operation (Eacc > 50MV/m) are being investigated.

Table of Paremeters for the X-band Main Linacs

	Phase-1	Phase-2
Final Energy / linac	250 GeV	500 GeV
Particles / bunch	0.7 - 1.1 E10	
Bunch Spacing	2.8 ns	
Bunches / pulse	95	
Pulse repetition rate	120 (- 150?) Hz	
Effective gradient	55 MV/m	
Klystron Power	75 MW	
Klystrons / linac	1600	3200
Structures / linac	2400	4800

- Tentative parameter choices made in 1997 - 1998 thru SLAC-KEK discussions:

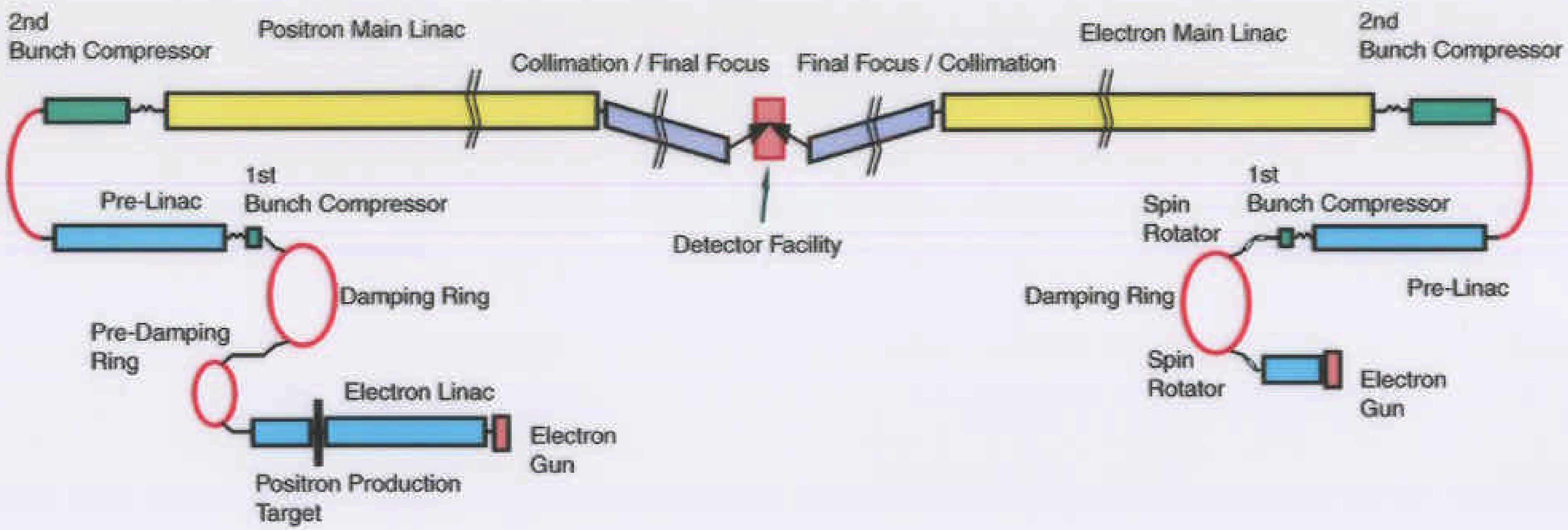
- Same RF system through Phase-1 and 2.

- Increased bunch spacing to 2.8 ns (was 1.4 ns)
  Beam-loading reduction: 28% --> 16 %
  Reduction of unloaded gradient: 85 --> 74 MV/m

- Increased klystron pulse width (was 0.96 μs)

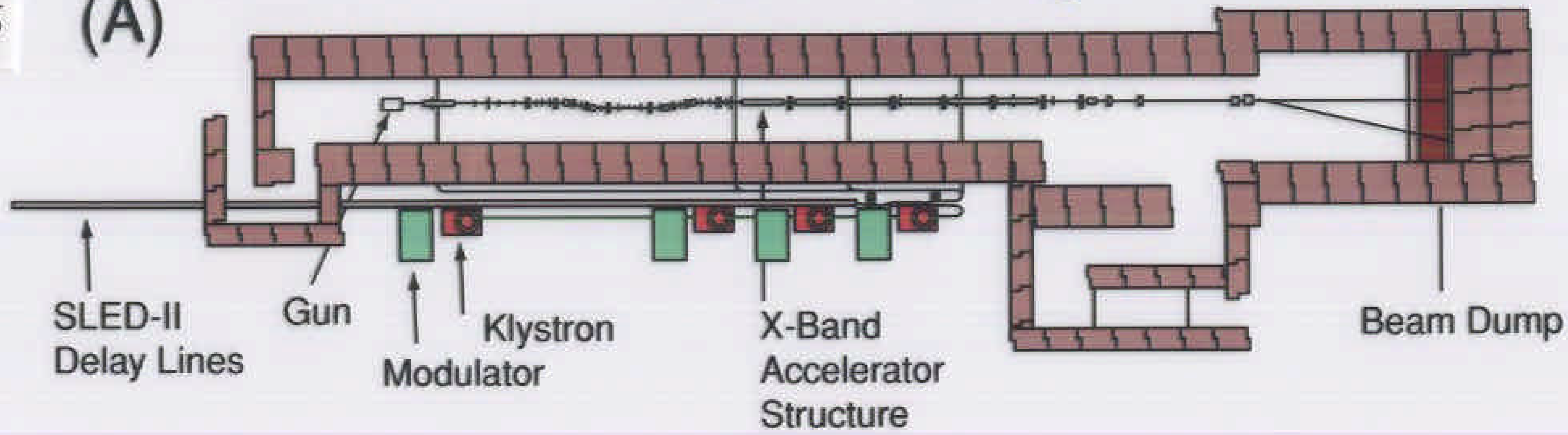
- Adoption of DLDS scheme
  ... leading to reduction of #klystron by 1/3.

- Adoption of Rounded DDS cell design
  ... leading to increased RF -> Beam efficienty (up 6%)

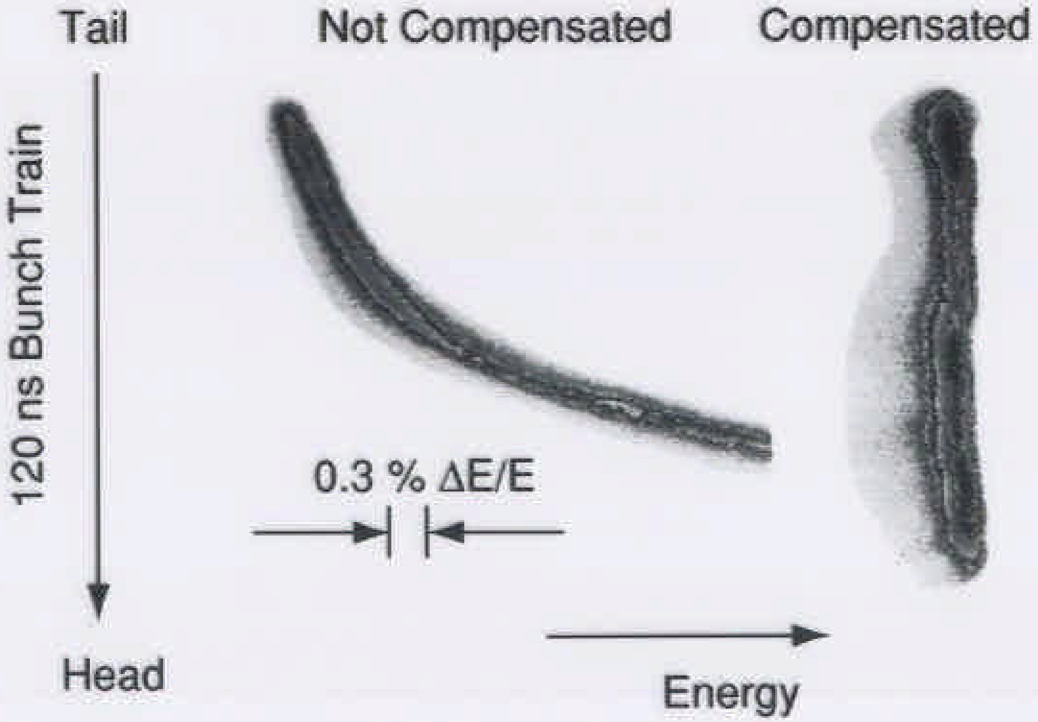

2nd
Bunch Compressor
Positron Main Linac
Collimation / Final Focus
Final Focus / Collimation
Electron Main Linac
2nd
Bunch Compressor
Pre-Linac
1st
Bunch Compressor
Detector Facility
Spin
Rotator
1st
Bunch Compressor
Damping Ring
Pre-Damping
Ring
Electron Linac
Electron
Gun
Positron Production
Target
Damping Ring
Pre-Linac
Spin
Rotator
Electron
Gun

NLCTA (SLAC)

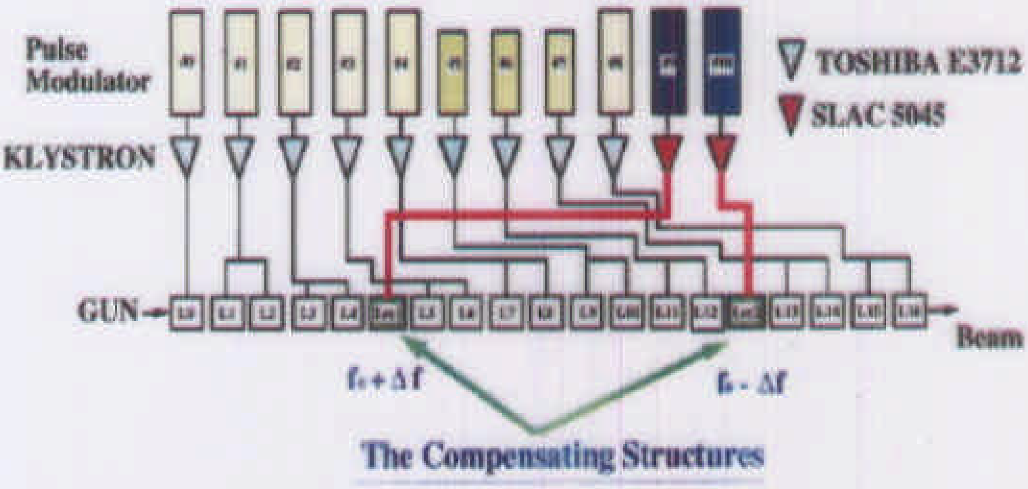
(A)



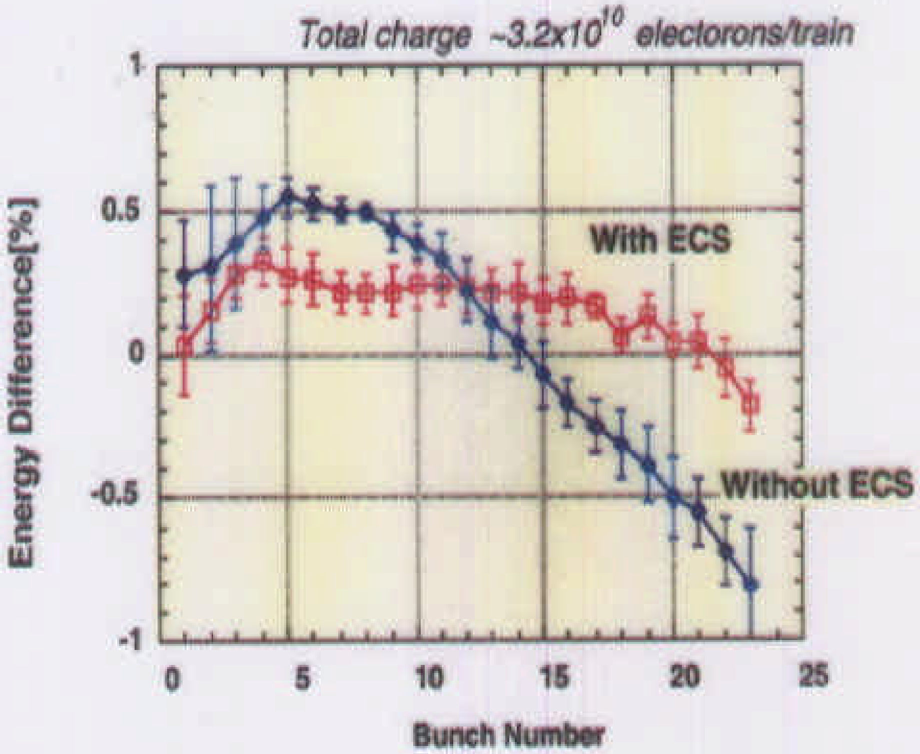
(B)

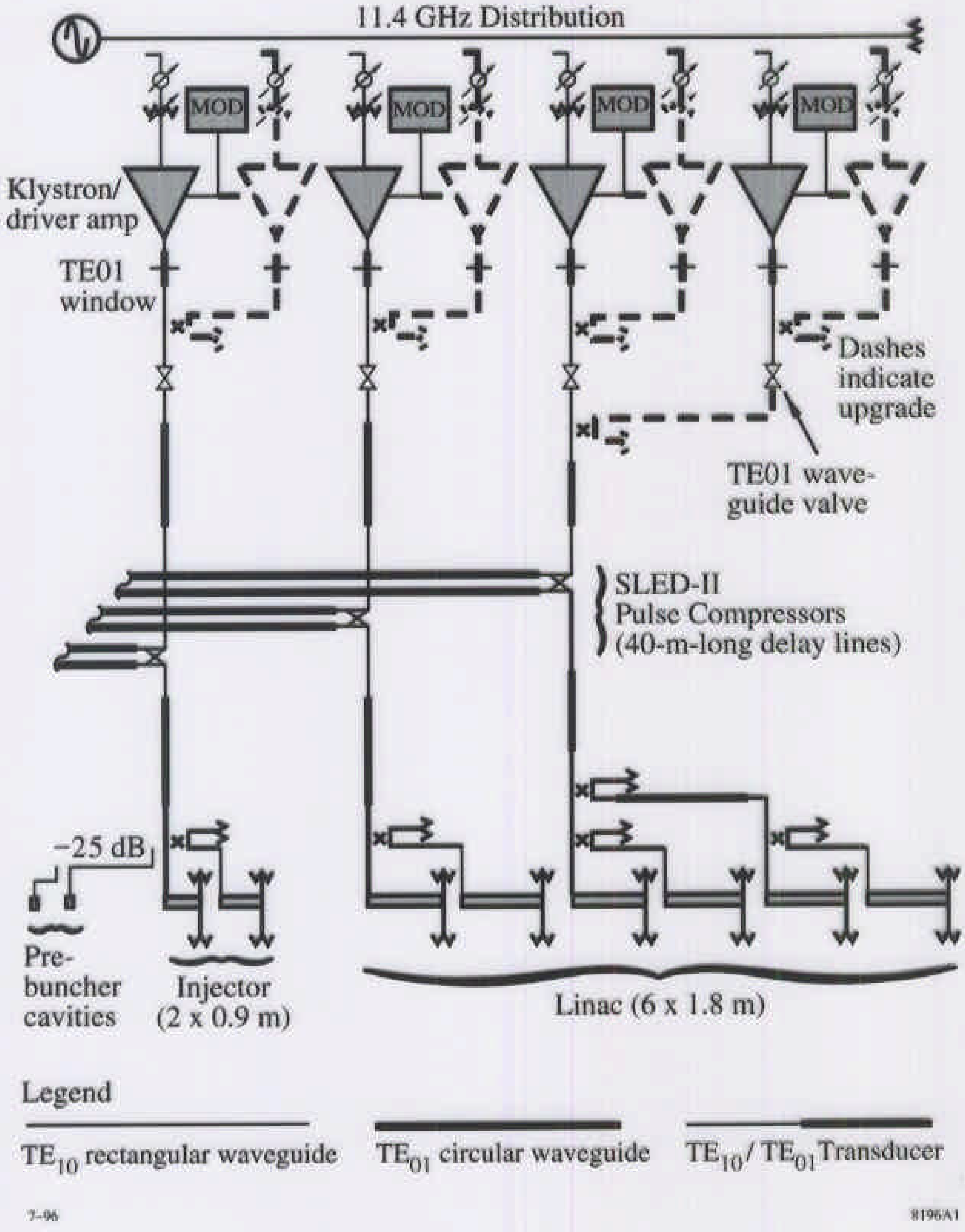


(A)

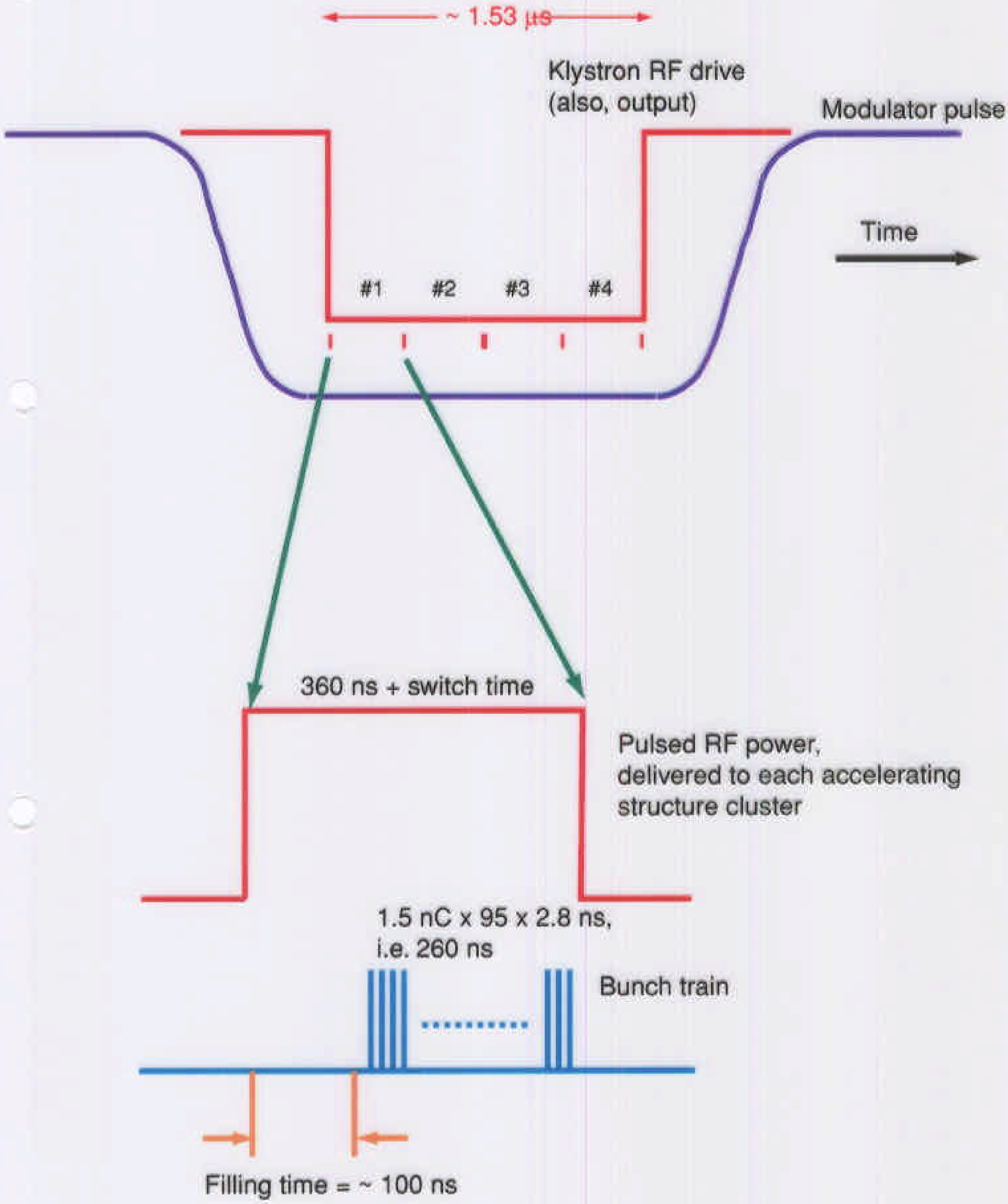

Pulse Modulator
KLYSTRON
TOSHIBA E3712
SLAC 5045
GUN
Beam
f₀ + Δf
f₀ - Δf
The Compensating Structures

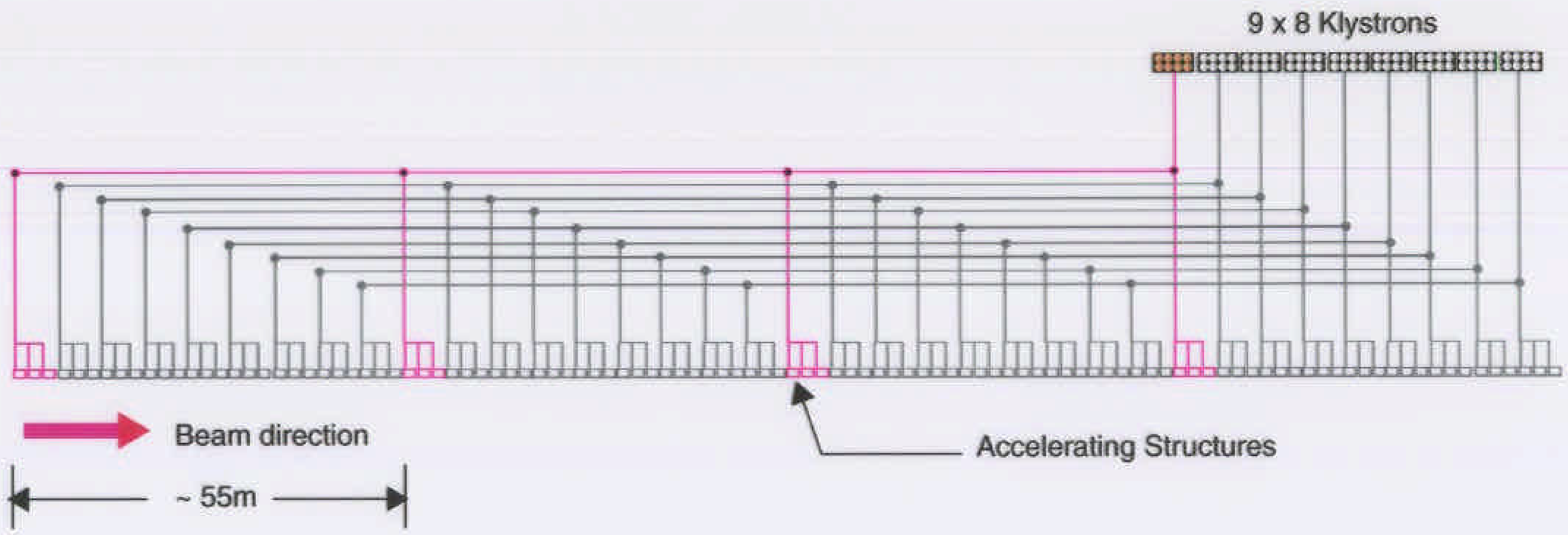
(B)


Total charge ~3.2x10^10 electorons/train
Energy Difference[%]
Bunch Number
With ECS
Without ECS
1
0.5
0
-0.5
-1
0
5
10
15
20
25


11.4 GHz Distribution
MOD
MOD
MOD
MOD
Klystron/
driver amp
TE01
window
Dashes
indicate
upgrade
TE01 wave-
guide valve
SLED-II
Pulse Compressors
(40-m-long delay lines)
−25 dB
Pre-
buncher
cavities
Injector
(2 x 0.9 m)
Linac (6 x 1.8 m)
Legend
TE10 rectangular waveguide
TE01 circular waveguide
TE10/ TE01 Transducer
7-96
8196A1

Relationship between the RF Power and Bunch Train

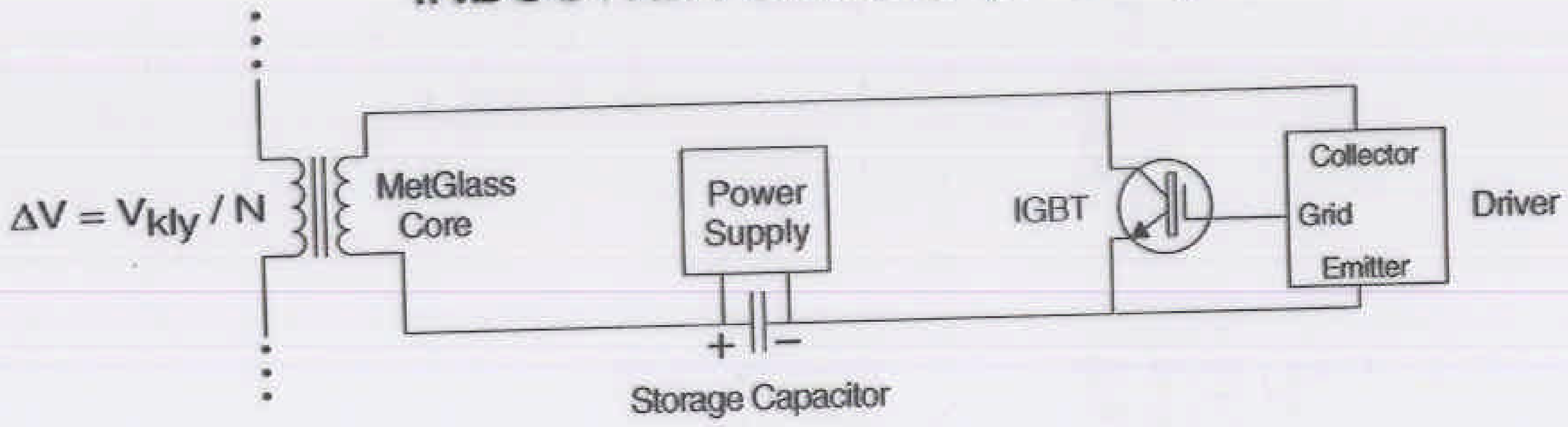



9 x 8 Klystrons
Beam direction
~ 55m
Accelerating Structures

INDUCTION MODULATOR :

SUM MANY LOW VOLTAGE SOURCES INDUCTIVELY

INDUCTION CIRCUIT (1 OF N)



10 CM

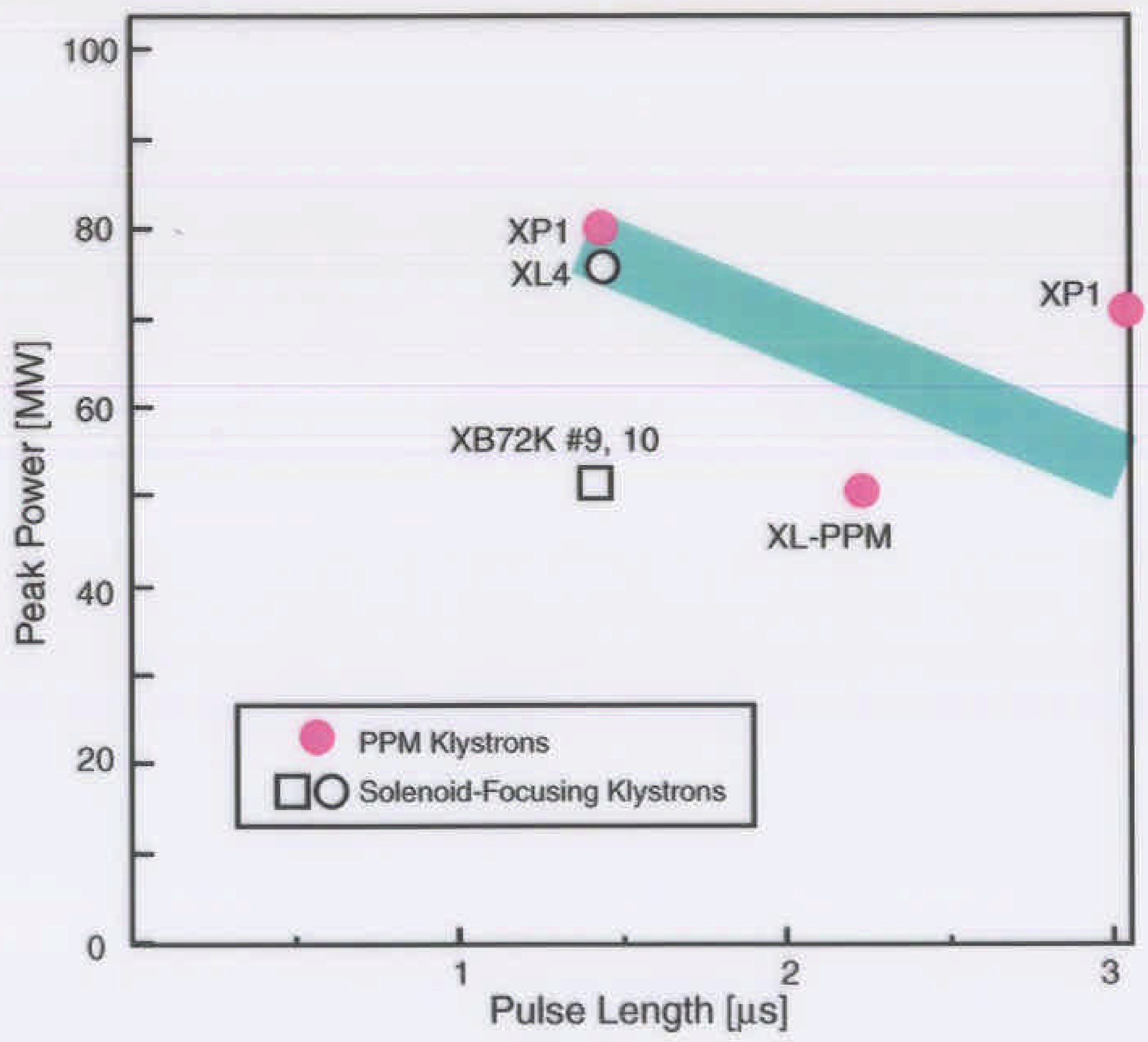
Dri Circuit

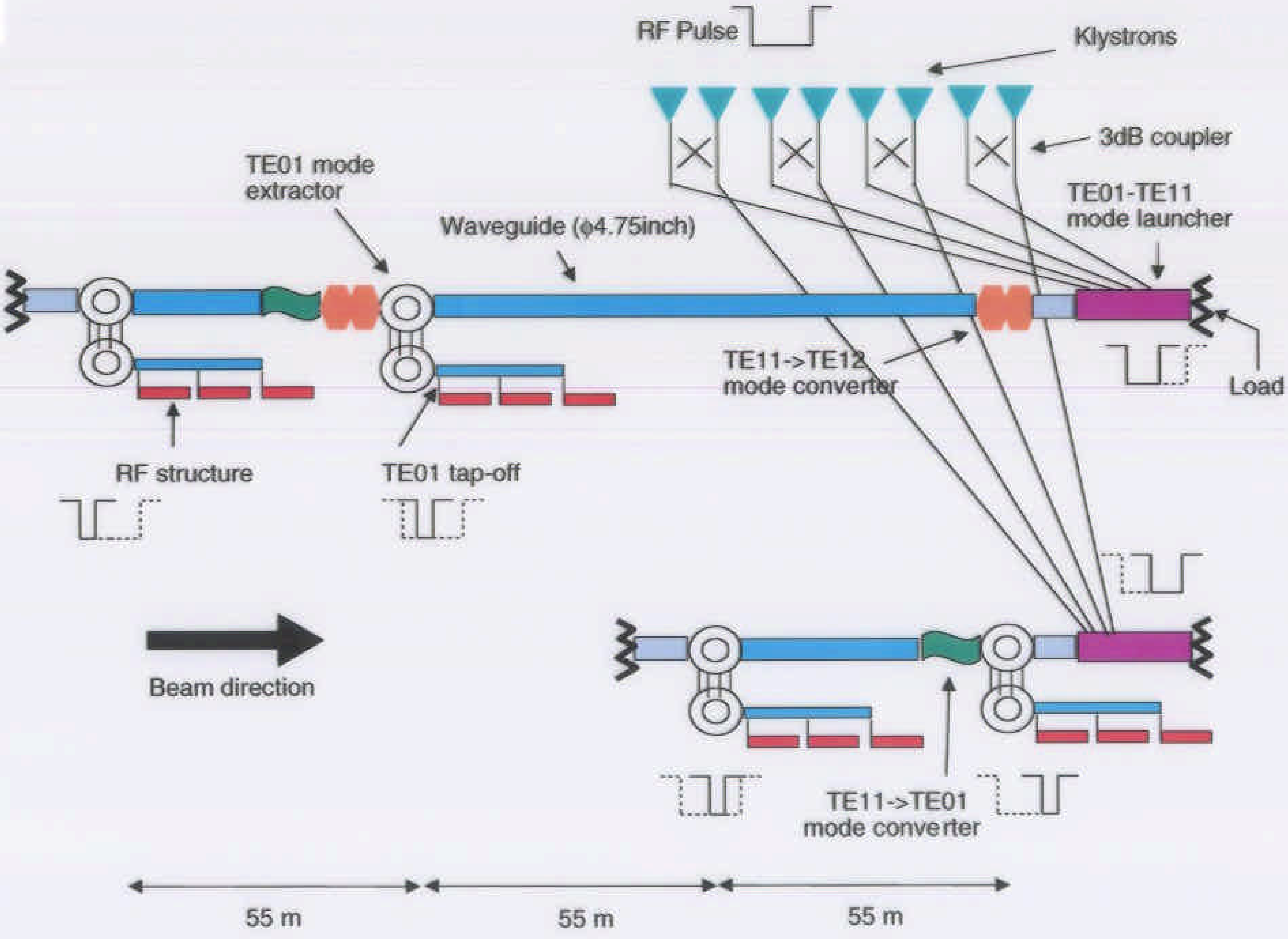
Isolated Gate Bipolar Transistor

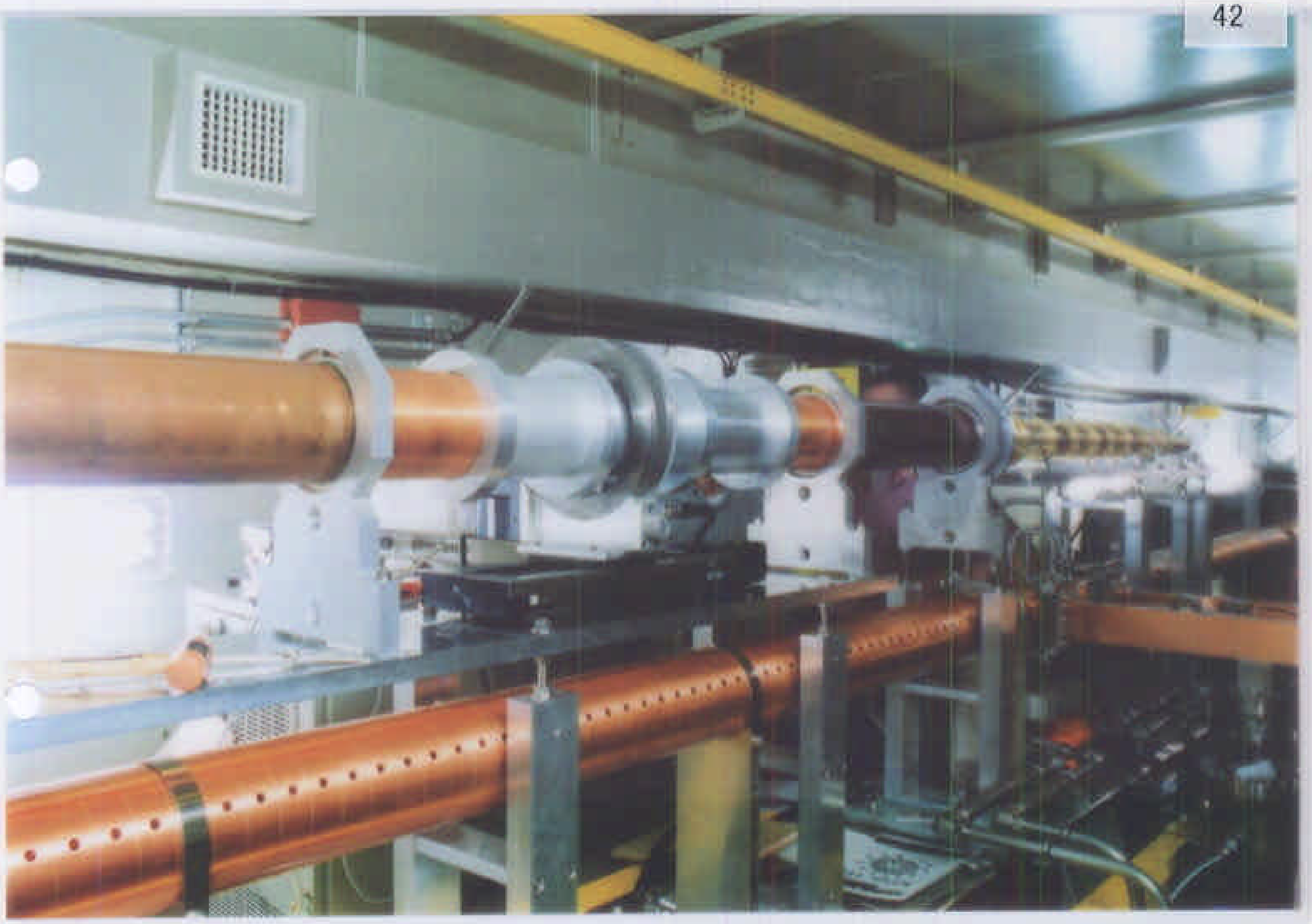
Rated: 3.3 kV @ 0.8 kA (DC)

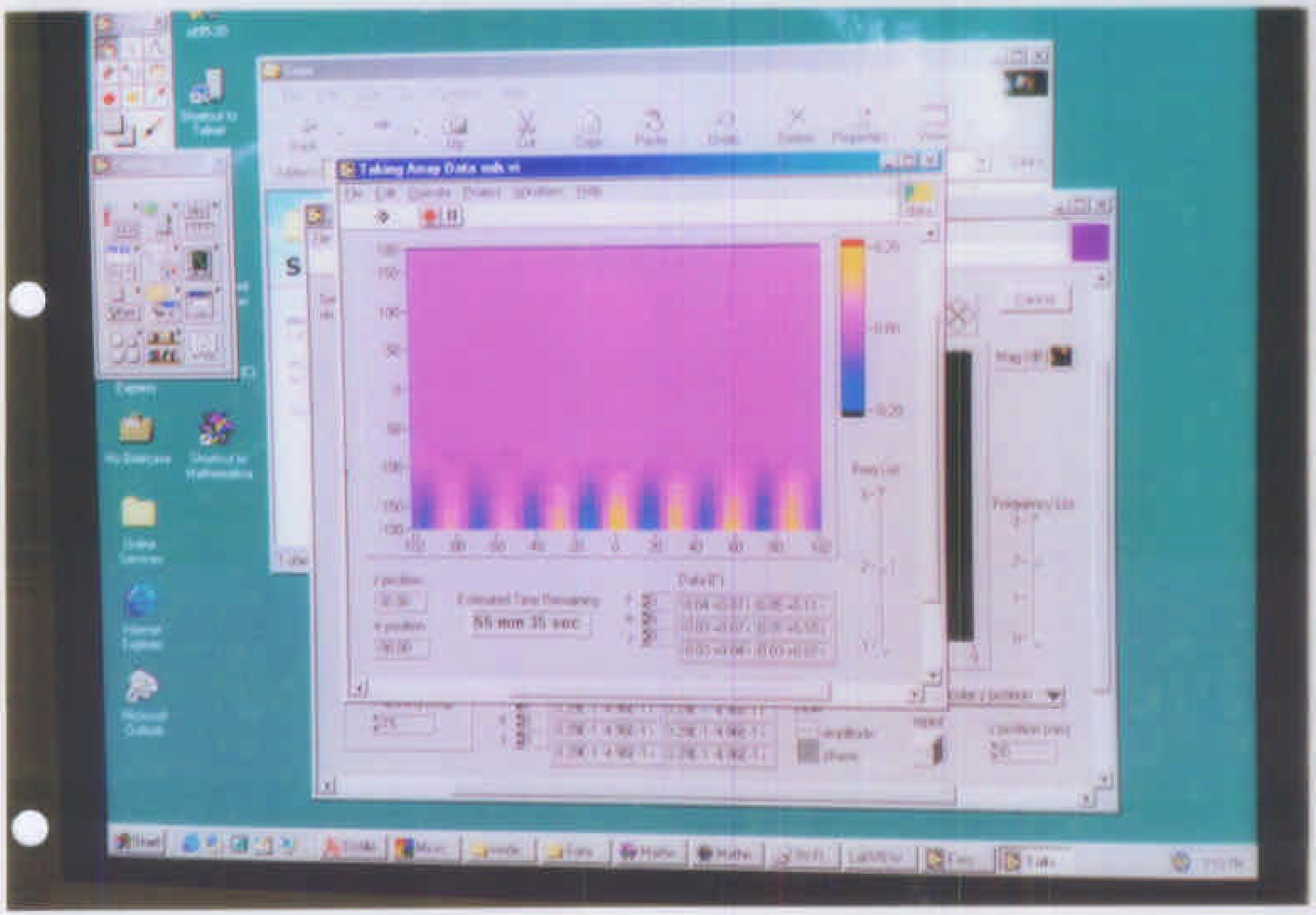
Tested: 2.0 kV @ 1.5 kA (Pulsed)

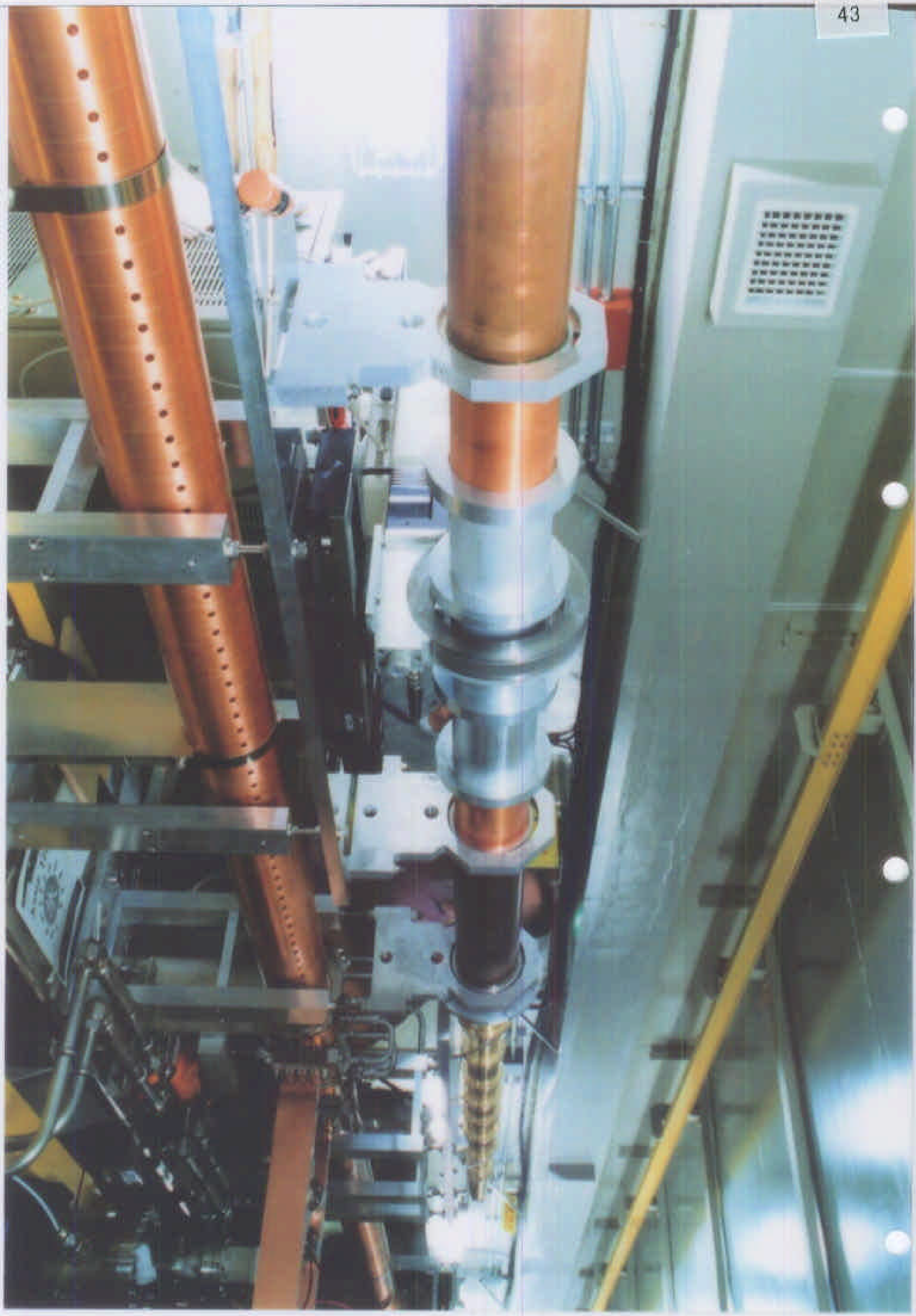
Future: 5.0 kV @ 2.0 kA (Pulsed)


100
80
60
40
20
0
Peak Power [MW]
1
2
3
Pulse Length [µs]
XP1
XL4
XP1
XB72K #9, 10
XL-PPM
PPM Klystrons
Solenoid-Focusing Klystrons

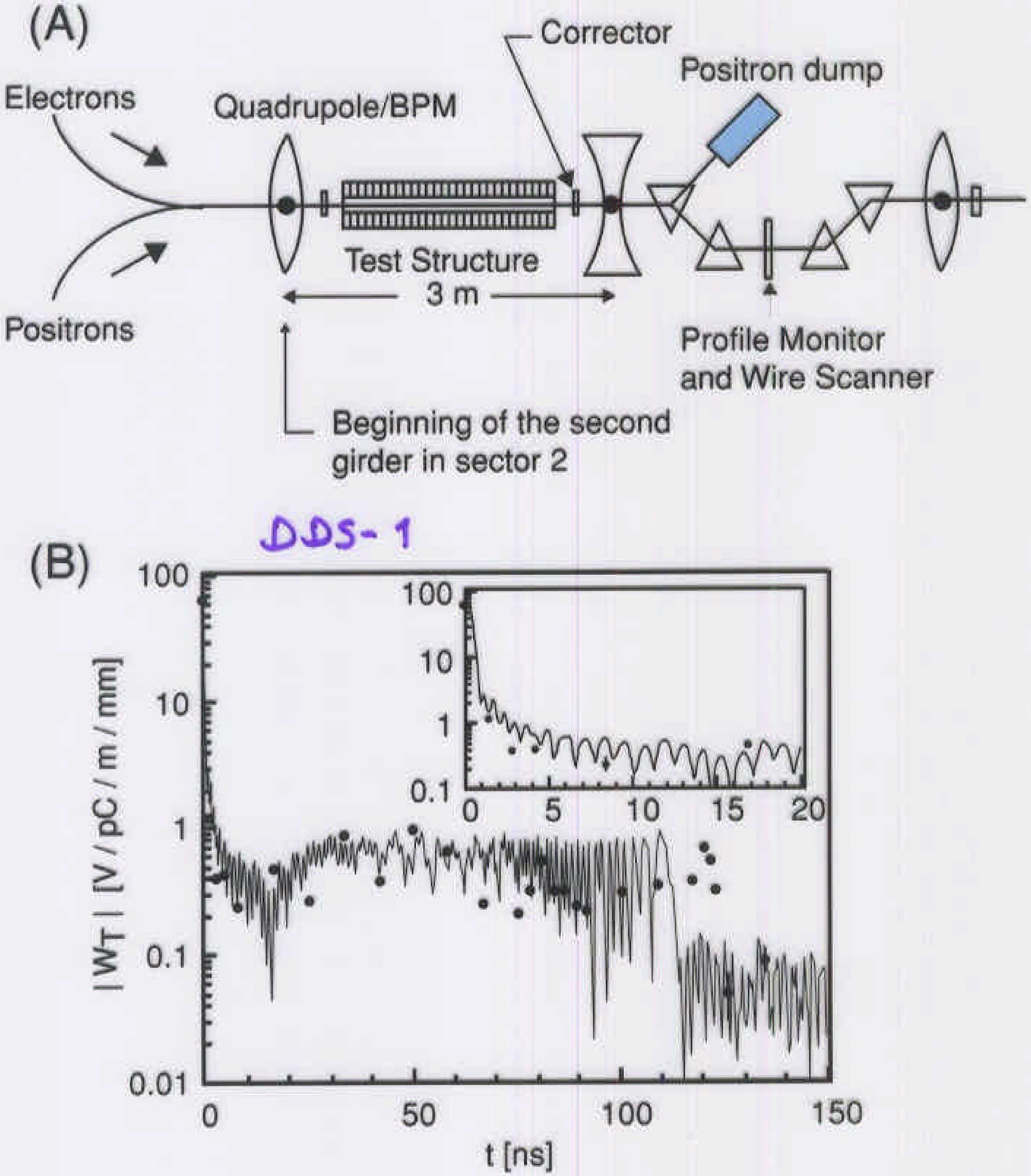

RF Pulse
Klystrons
3dB coupler
TE01 mode
extractor
Waveguide (φ4.75inch)
TE01-TE11
mode launcher
TE11->TE12
mode converter
Load
RF structure
TE01 tap-off
Beam direction
TE11->TE01
mode converter
55 m
55 m
55 m

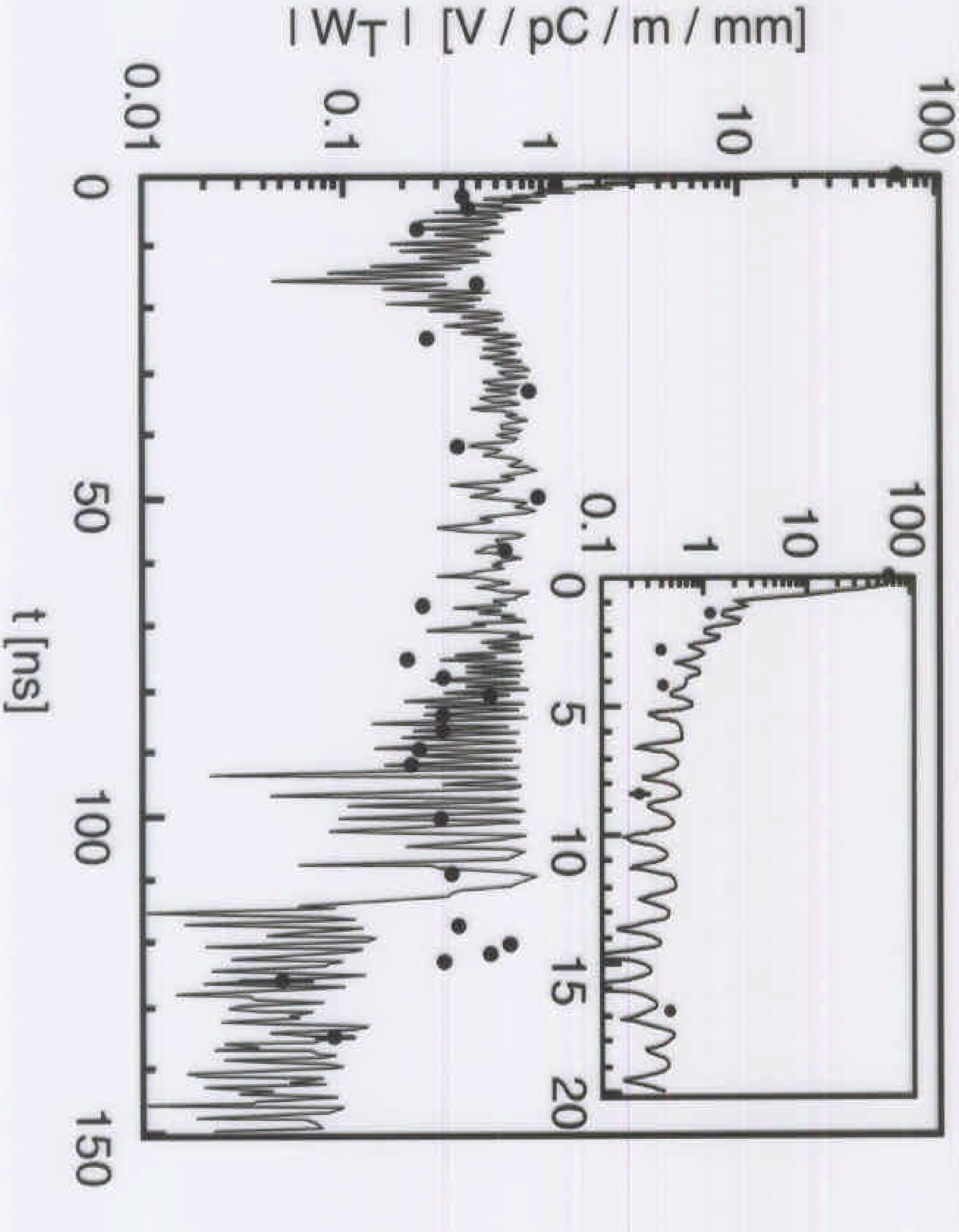



Taking Array Data

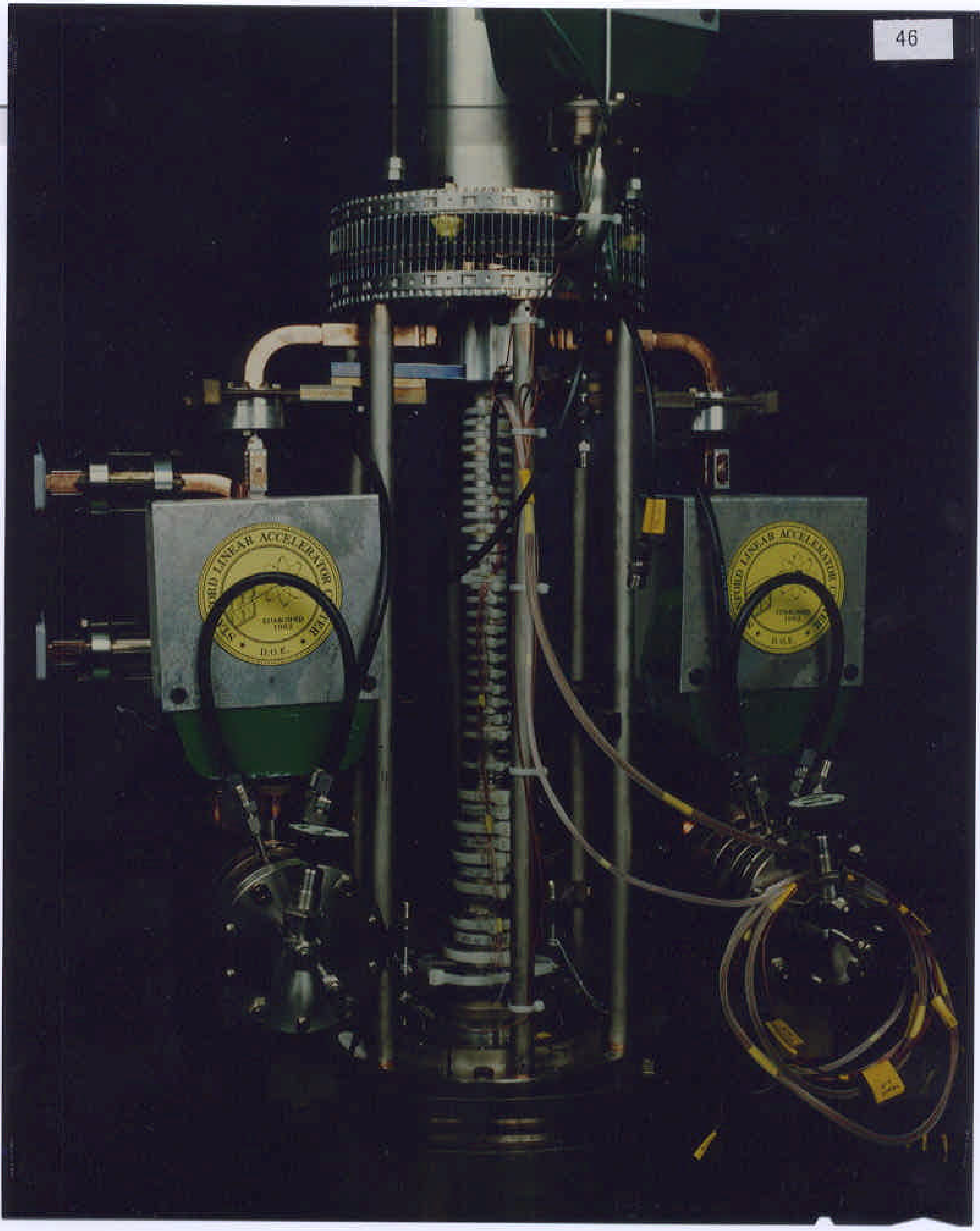


ASSET (SLAC)


(A)
Electrons
Positrons
Quadrupole/BPM
Corrector
Positron dump
Test Structure
3 m
Profile Monitor
and Wire Scanner
Beginning of the second
girder in sector 2
DDS-1
(B)
| W_T | [V / pC / m / mm]
t [ns]
100
10
1
0.1
0.01
0
50
100
150
0
5
10
15
20



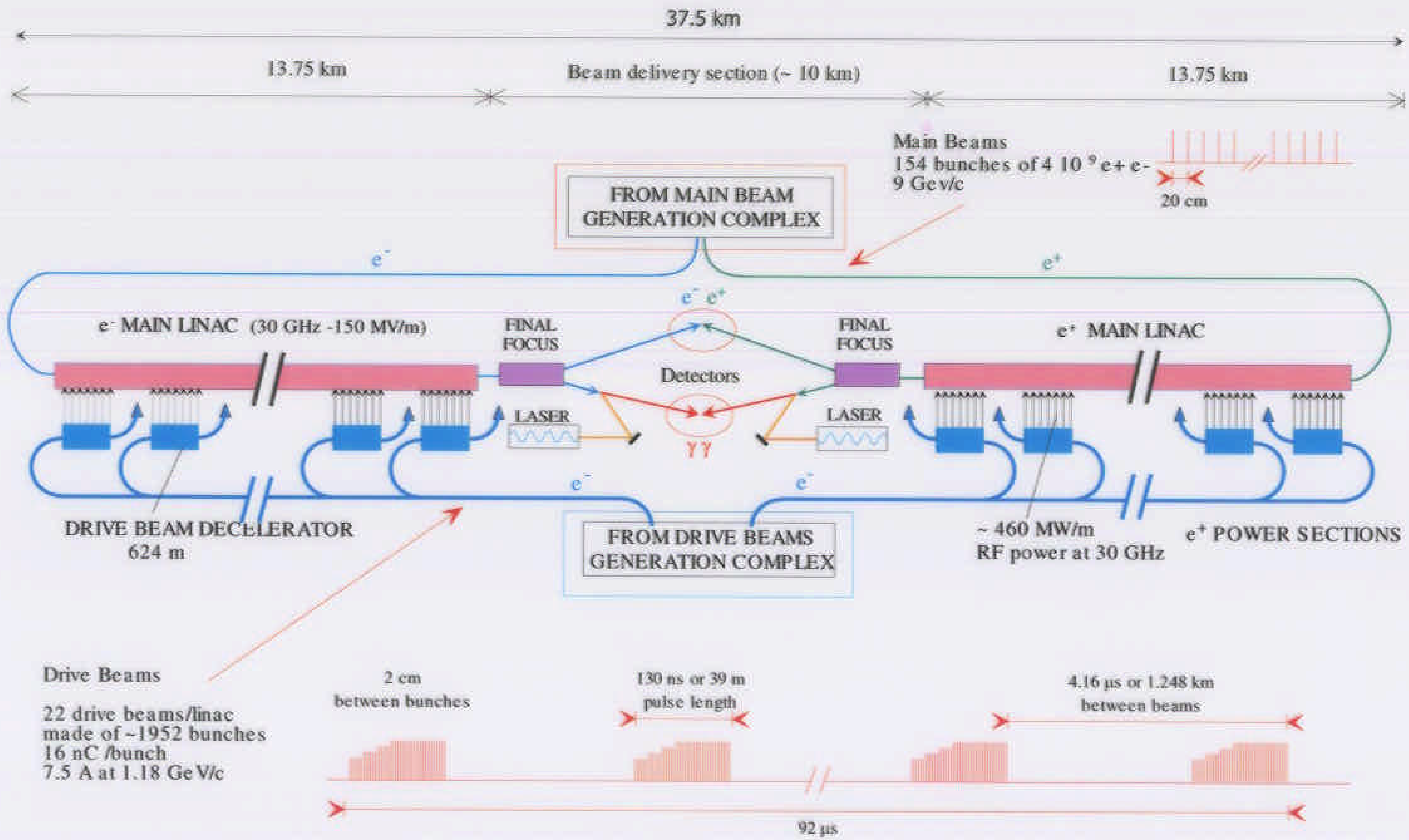
| W_T | [V / pC / m / mm]
t [ns]
0.01
0.1
1
10
100
0
50
100
150
0.1
1
10
100
0
5
10
15
20


ACCELERATOR
D.O.E.

2D. CLIC

- NC structure driven at high-gradient (150 MV/m) 30 GHz
  - Reduced linac length (two-linac length still at 27.5 km even for 3 TeV - 150 MV/m).
- RF generation of 30 GHz as the power extracted from a high-intensity, low-energy drive beam (937 MHz NC linac).
  - Considered the most cost-effective for producing multi-TeV beams.
- CTF1 demonstrated the feasibility of TBA concept by 1995 :
  - 76 MW of 30 GHz RF power --> 125 MV/m.
- CTF2 is currently in operation for testing multi-bunch drive beam operation (total 373 nC)
  - Power extracted from drive beam: 27 - 22 MW
    Power into CAS: 21 - 17 MW
    Field in CAS: 57 - 51 MV/m
- CTF3 is under study for testing all major parts of the CLIC RF power scheme.

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



CLIC Parameters

Beam param. at I.P.	0.5 TeV	1 TeV	3 TeV	5 TeV
Luminosity (10^{34}cm^{-1}s^{-1})	1.4	2.7	10.0	10.0
Mean energy loss (%)	4.4	11.2	31	37
Photons /electrons	0.7	1.1	2.3	3.2
Coherent pairs per X	700	$3\ 10^6$	$6.8\ 10^8$	$1.8\ 10^9$
Rep. Rate (Hz)	200	150	100	50
10^9 $e^\pm$ / bunch	4	4	4	4
Bunches / pulse	154	154	154	154
Bunch spacing (cm)	20	20	20	20
H/V ε_n (10^{-8} rad.m)	200/2	130/2	68/2	78/2
Beam size (H/V) (nm)	202/2.5	115/1.75	43/1	31/0.78
Bunch length (μm)	30	30	30	25
Accel.gradient (MV/m)	150	150	150	172
Two linac length (km)	5	10	27.5	40
Power / section (MW)	229	229	229	301
RF to beam effic. (%)	24.4	24.4	24.4	21.3
AC to beam effic. (%)	9.8	9.8	9.8	8.5
AC power (MW)	100	150	300	290

Features of CLIC scheme

The CLIC scheme has two very distinctive features

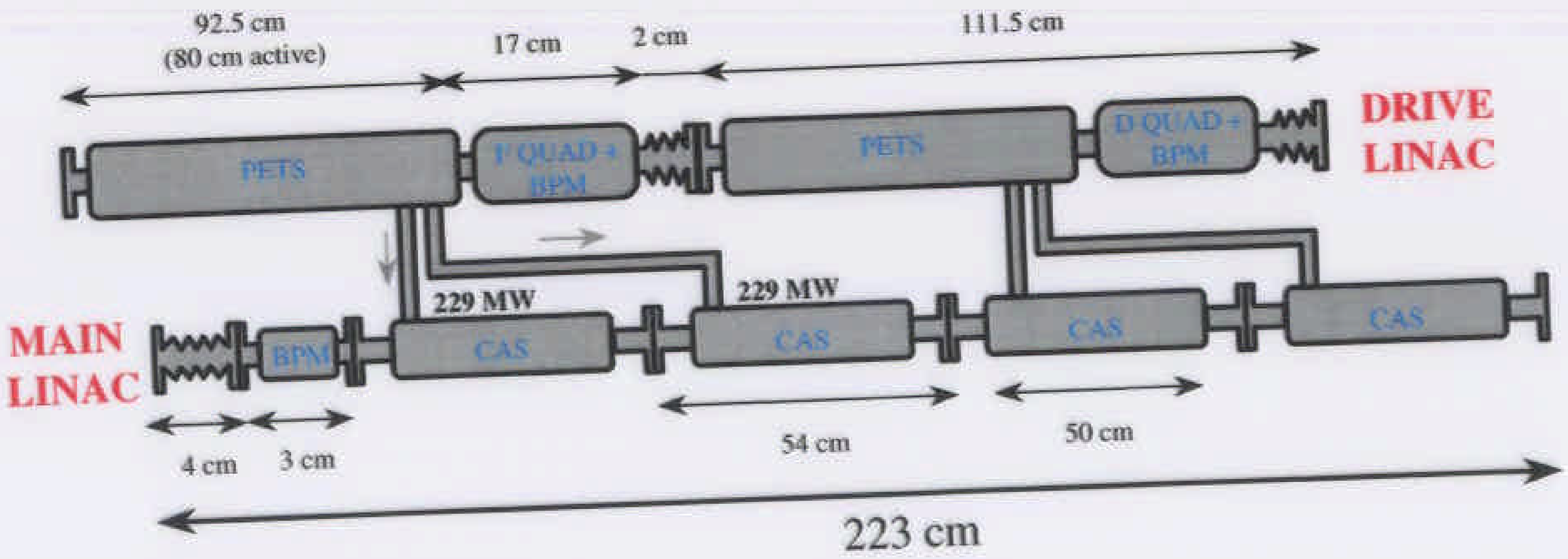
- It accelerates the beam using high frequency (**30 GHz**) normal-conducting structures operating at high fields (**150 MV/m**) - this reduces the **LENGTH** and in consequence, the **COST** of the linac.

  (For 3 TeV - 150 MV/m - two-linac length 27.5 km)

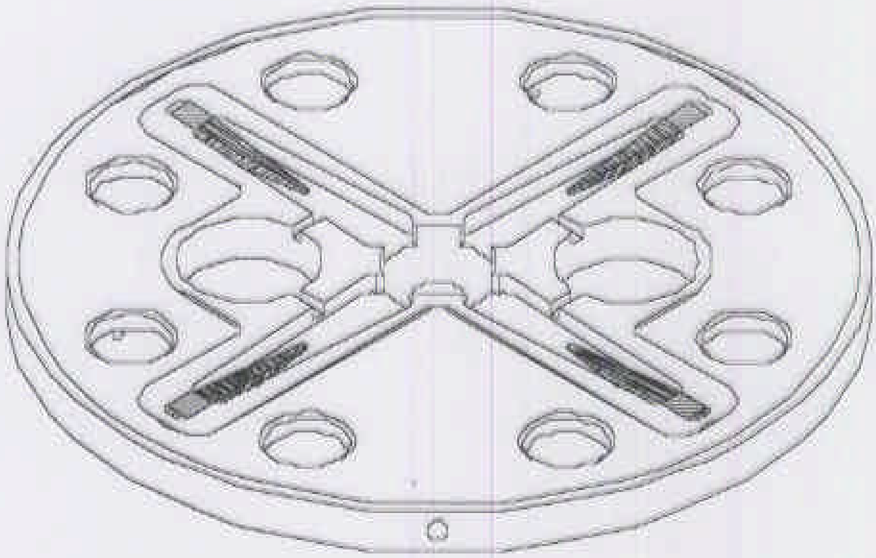
- It extracts its RF power from a **high-intensity low-energy drive beam** running parallel to the main linac. This RF power generation scheme we believe to be the most **cost effective** way to produce **multi-TeV** beams.

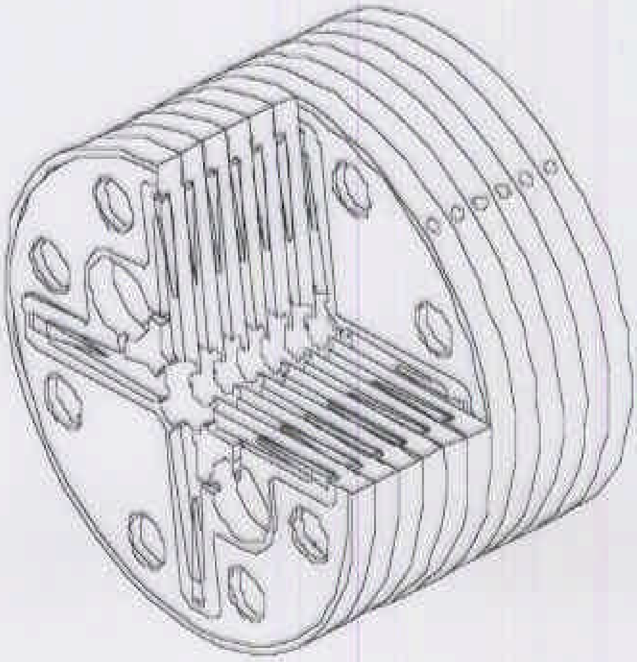
CLIC Two-Beam Acceleration (TBA) scheme

- CLIC main linac made up from series of 2.23m long two-beam modules - one shown below.
- RF power to feed the 30 GHz accelerating structures extracted by special decelerating structures from high-intensity/low-energy drive beam running parallel to main beam.
- Two-beams separated by about 50 cm
- One power extracting structure feeds two main linac accelerating structures.
- Drive beam dumped after extracting about 85 % of its energy.

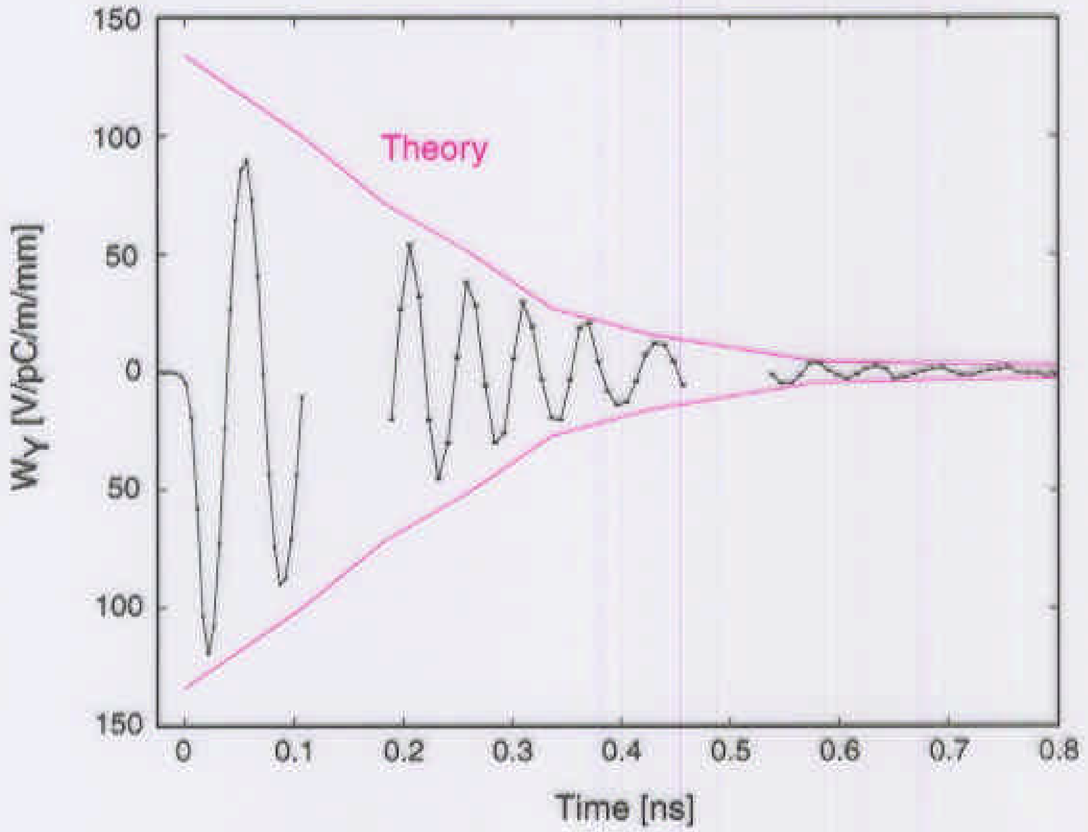


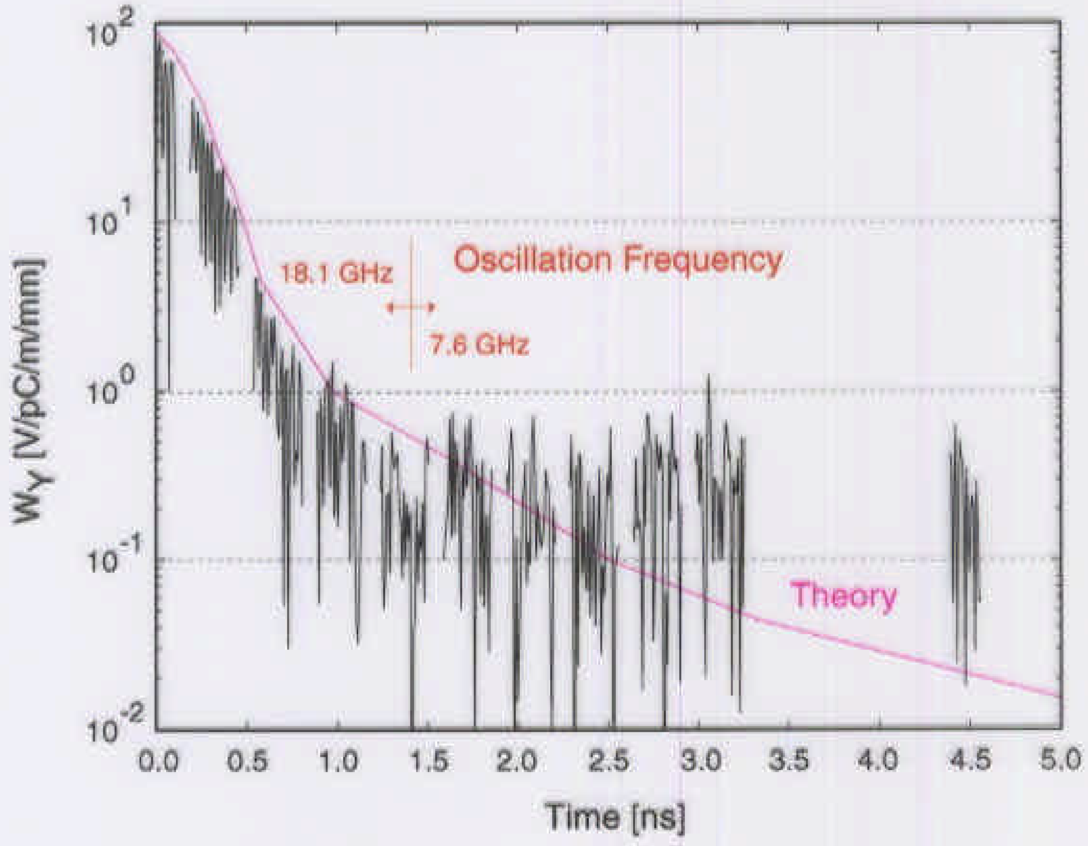
CLIC TDS
Tapered Damped Structure



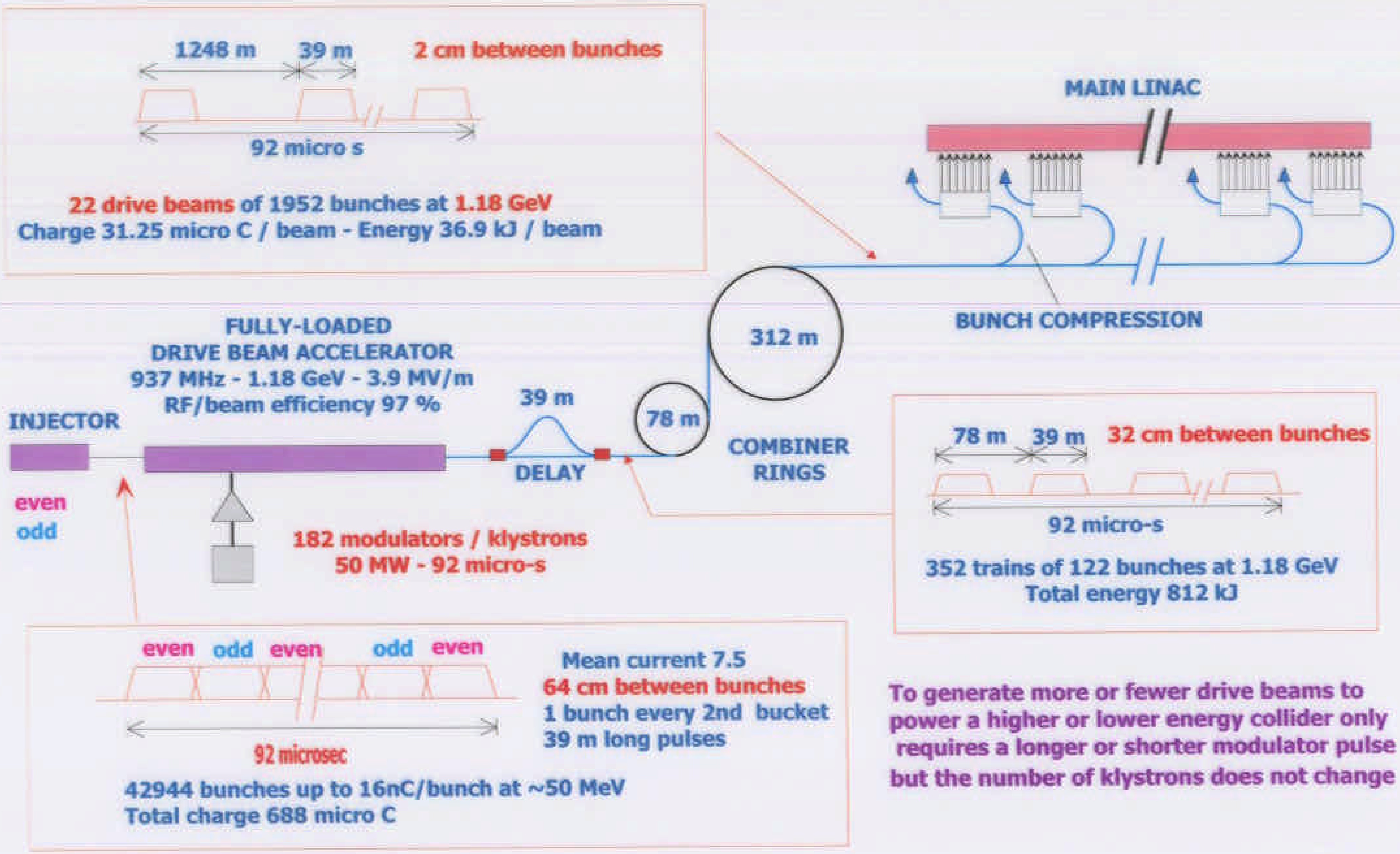


CERN TDS Structure



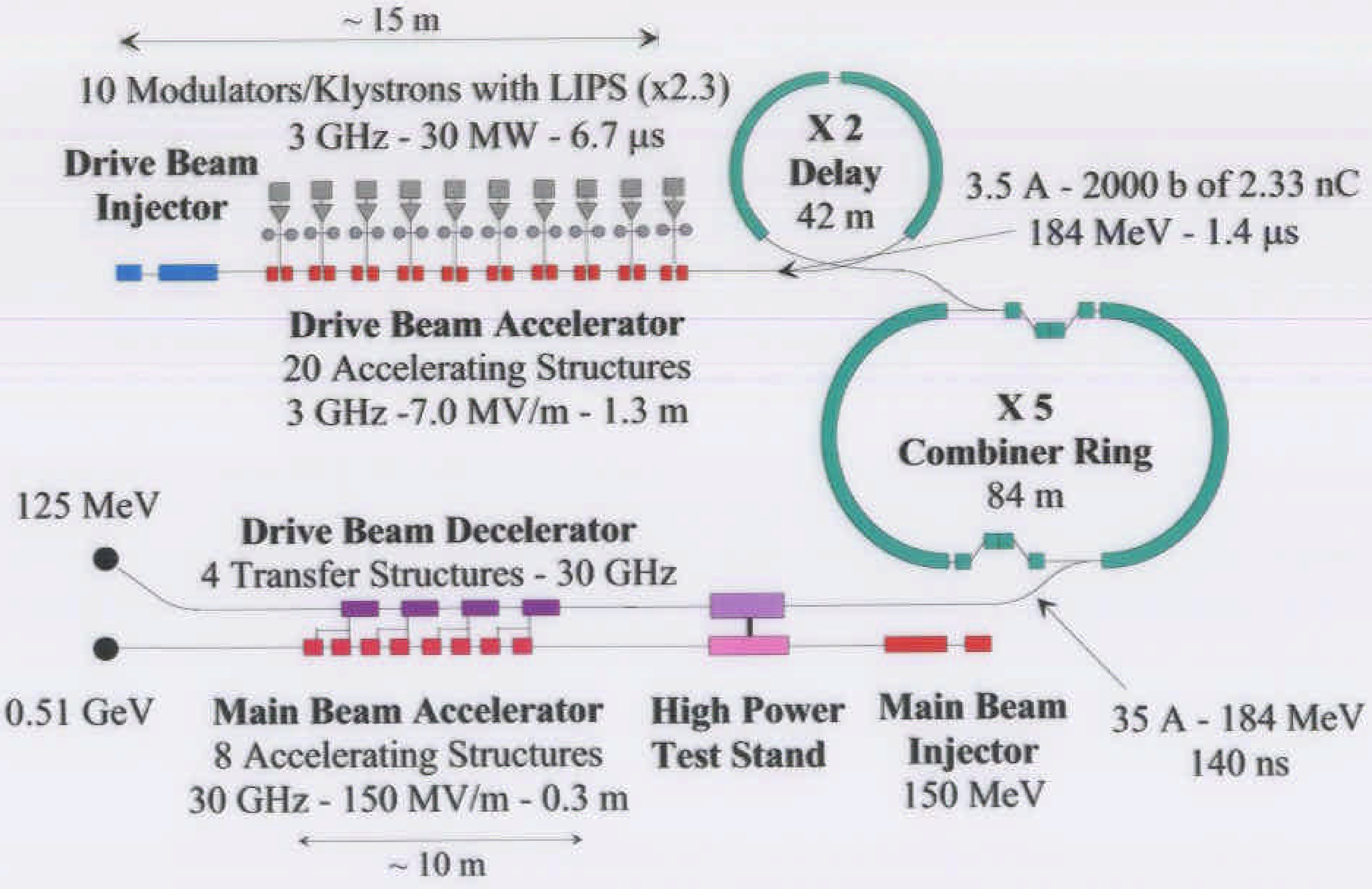


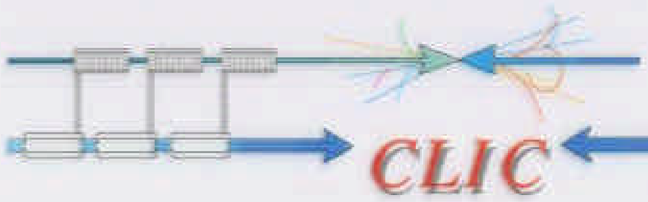
CLIC RF POWER SOURCE FOR 3 TeV COLLIDER



To generate more or fewer drive beams to power a higher or lower energy collider only requires a longer or shorter modulator pulse but the number of klystrons does not change

CLIC TEST FACILITY - CTF 3 - Nominal
Test of Drive Beam Generation, Acceleration & RF Multiplication by a factor 10





Main challenges of CLIC scheme:

- To design a reasonable length beam delivery section for 3 TeV.
- To create and collide beams with very small spot sizes ($\sigma_{X/Y}$ = 43/ 1nm) at IP.
- To operate physics detectors with collisions every 0.7 ns.
- To extract meaningful physics data with a strong beam/beam interaction (δ_B~31%).
- To generate ultra-small emittances ($\varepsilon_{n\ H/V}$ ~ 500/10 nrad.m) from damping rings.
- To preserve this emittance in linac in presence of strong transv. wake-fields ($W_T \sim f^3$)
- To develop the necessary 30 GHz technology - and in particular to build **Accelerating structures, Power-extracting structures, and BPMs.**
- To demonstrate accelerating gradients of 150 MV/m for 130 ns.
- To demonstrate feasibility of new DB generation and power production scheme.

3. Beyond Next-Generation LCs

3a. Pulsed heating of accelerating structure surface

A general consensus is that in terms of (suppression of) dark current capture / breakdown, we may scale

$$E_{acc} \sim \lambda^{-1}.$$

However, instantaneous temp rise had better be

$$\Delta T < 40 \sim 120\ K. \quad \cdots \text{ CONSTANT}$$

for preventing plastic deformation of OFC, also.
The typical scaling of ΔT is

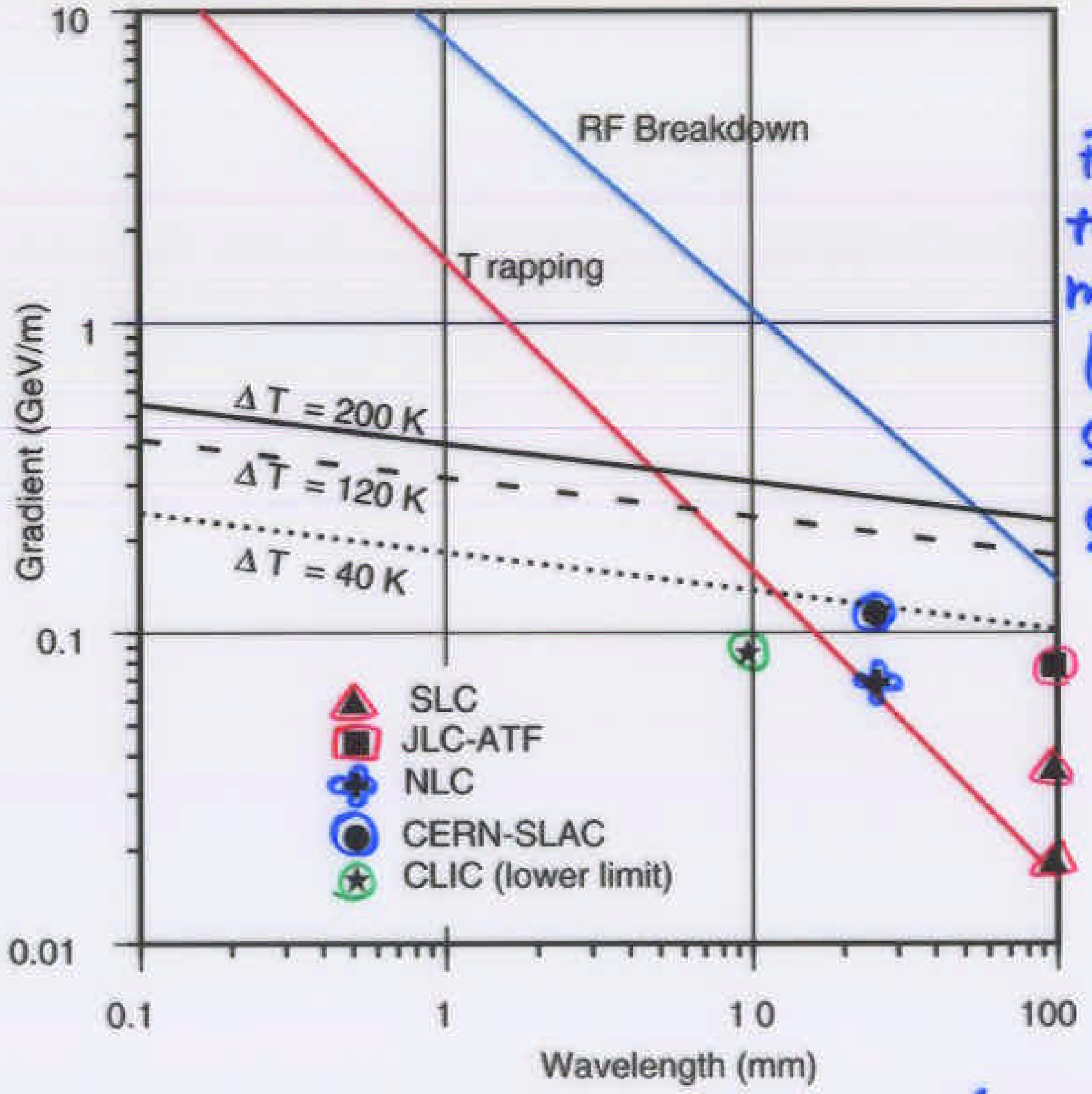
$$\Delta T \sim E_{acc}^{2} \lambda^{1/4}.$$

So, to keep ΔT below a certain constant, we need to (are likely) observe

$$E_{acc} \sim \lambda^{-1/8}.$$

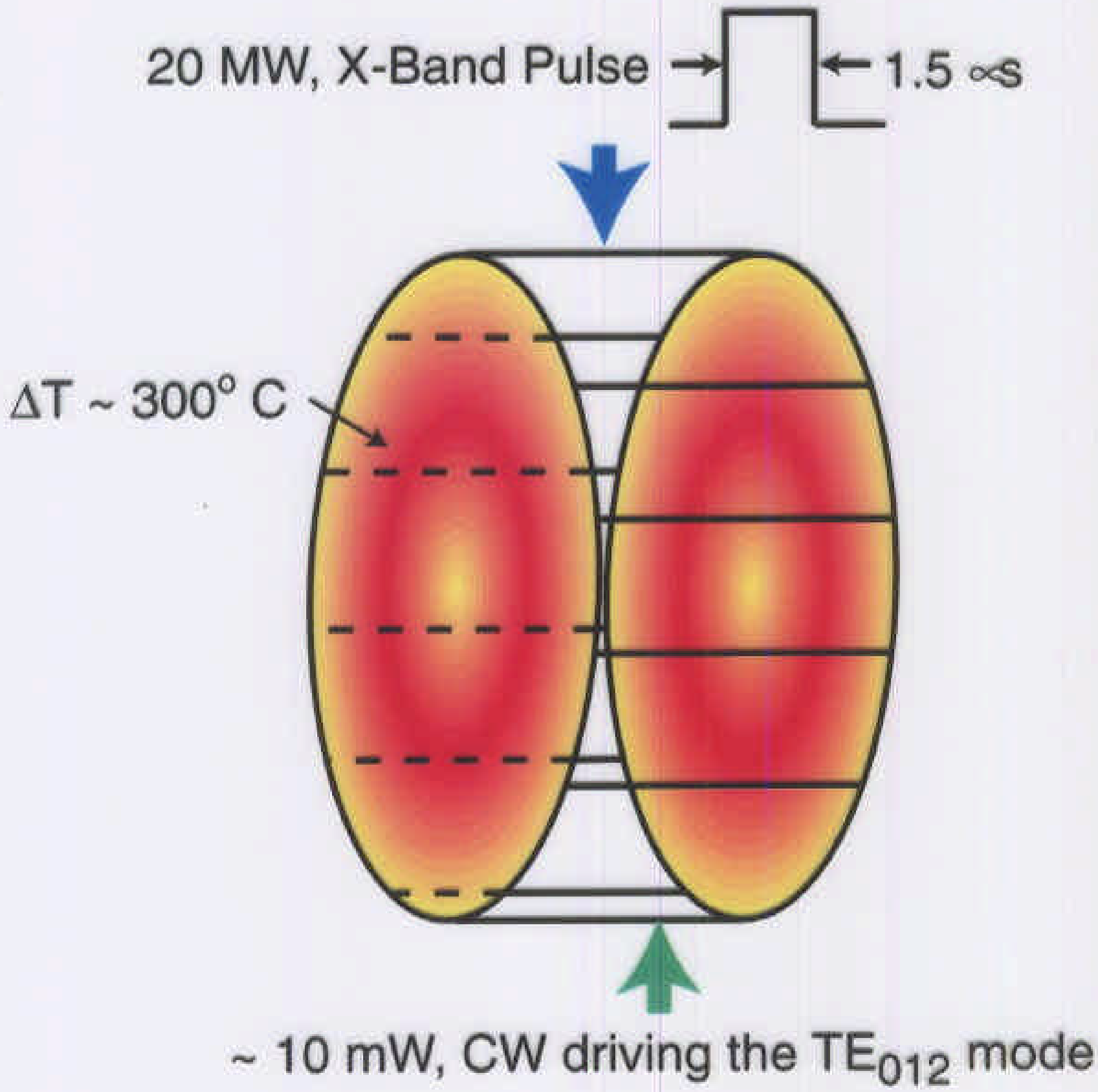
What does this mean?

- We may not be allowed to be too aggressive in pushing OFC structures.
- More Exp data needed (work under way by R.Siemann, et al @ SLAC). SLAC-PUB-8070
- Use of "harder" material, more rubust against plastic deformation (such as "glicop") ?

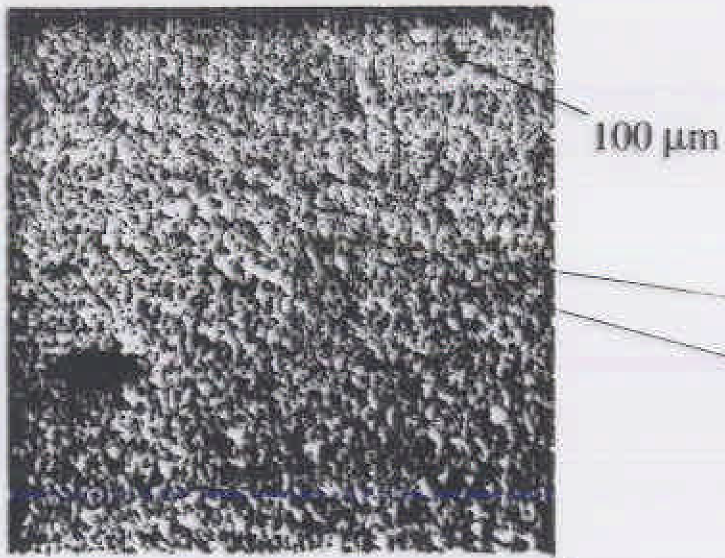


Pulse heating is thought to be the most serious limit to scaled solid-state structures

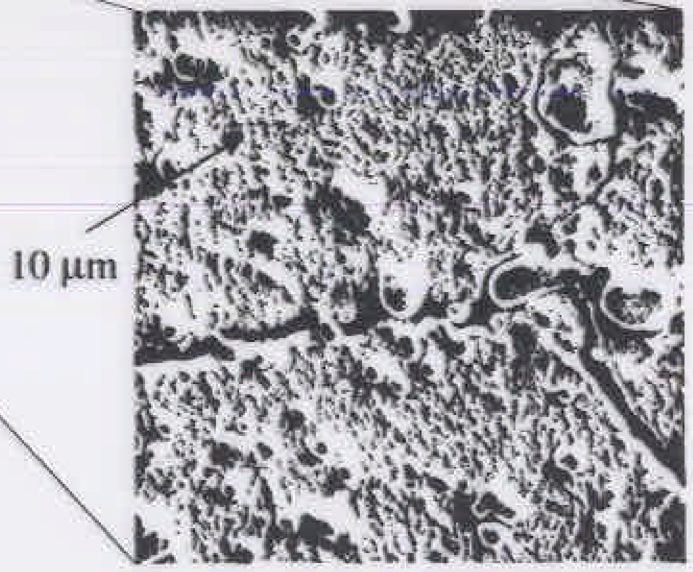
(Courtesy D.Whittum)

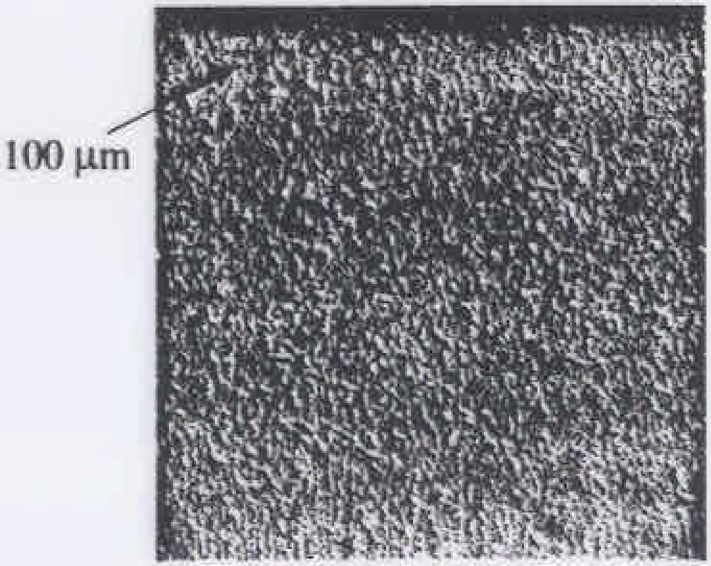

20 MW, X-Band Pulse
1.5 ∝s
ΔT ~ 300° C
~ 10 mW, CW driving the TE012 mode

Scanning Electron Microscope
5 keV, secondary emission



Area of Maximum
Temperature Rise





Center of Endcap
No Damage

3b. W-band Technology

80 GHz --> $\lambda = 0.38$ cm

Aiming at reduced power consumption and higher accelerating gradient.

- W-band "sheet-beam" klystron R&D
  - Conceptual studies (SLAC).
- Accelerating structure (mm-wavelength, sub-μm tolerance)
  - LIGA (Deep X-ray lithography) and other micro-machining techniques

    Fabrication testing (SLAC, TU Berlin, Sandia - Livermore, SRRC-Taiwan)

3c. Plasma-based Accelerator

Inject photons or charged particle beams into plasma and create strong wakefields.

Transverse wakefield --> (de-)focussing effects
Longitudinal wakefield --> acceleration

- 100 GV/m for ~0.1mm ΔE ~ 100 MeV (Modena, Nakajima) ~'94
- Some interesting experimental results emerging. (CERN, LBNL, UCLA, USC, SLAC...)

Accelerator Research Department B

W-BAND = 80GHZ

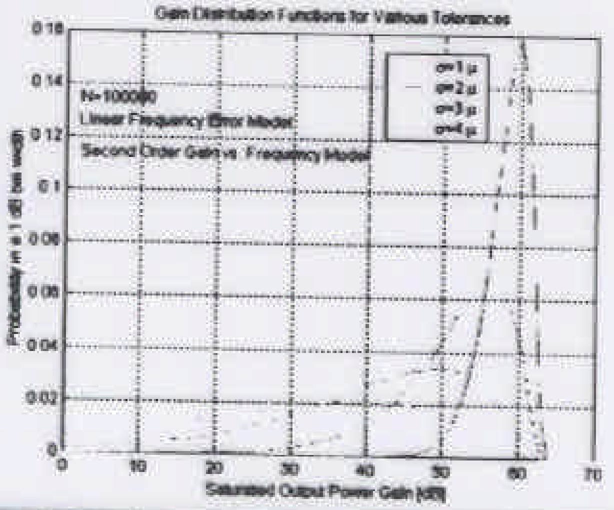
W-Band Sheet Beam Klystron Development

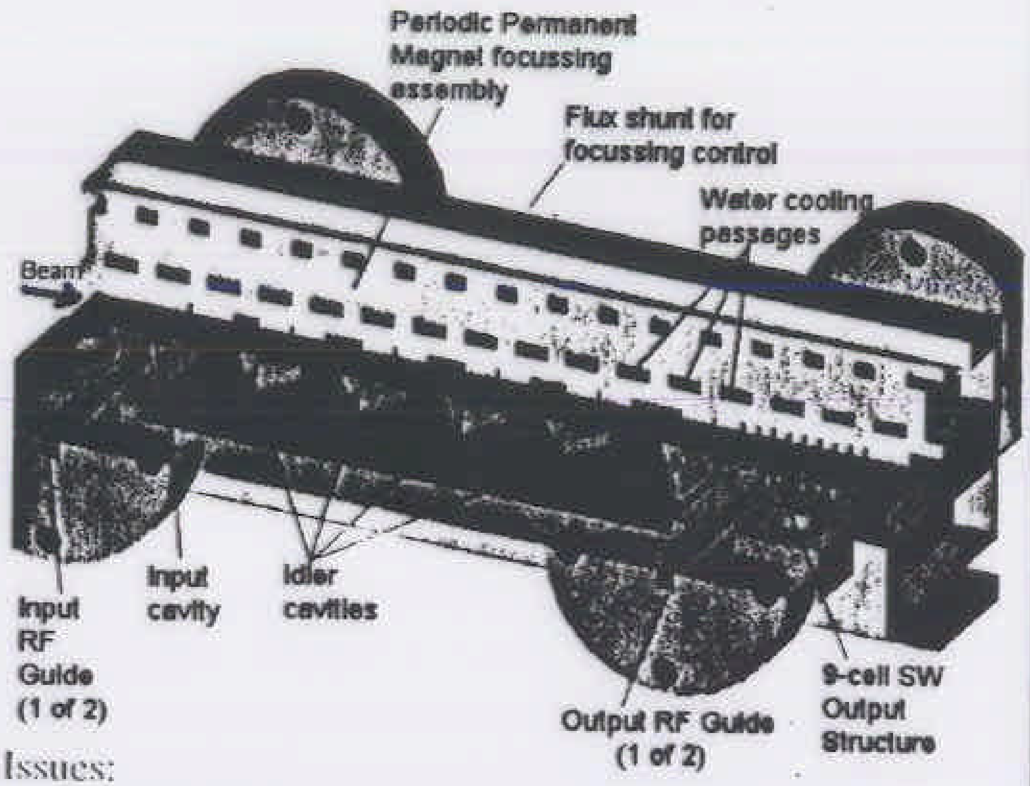
Goal:

Develop a high-power mm-wave source for accelerator research and radar applications

Source Parameters:

Output Power:	**1 MW**
Input Power:	**0.5 Watt**
Efficiency (PAE):	**49%**
Operating frequency:	**91.392 GHz**
Bandwidth (3 dB):	**0.2 GHz**
Net Gain:	**63 dB**
Most probable gain with 1μm RMS dimensional accuracy:	58.4 dB





Key Issues:

RF Circuit fabrication → focus of present research effort

Tolerances: ~1 μm RMS

Surface quality: 4-16 μ-inch interior finish

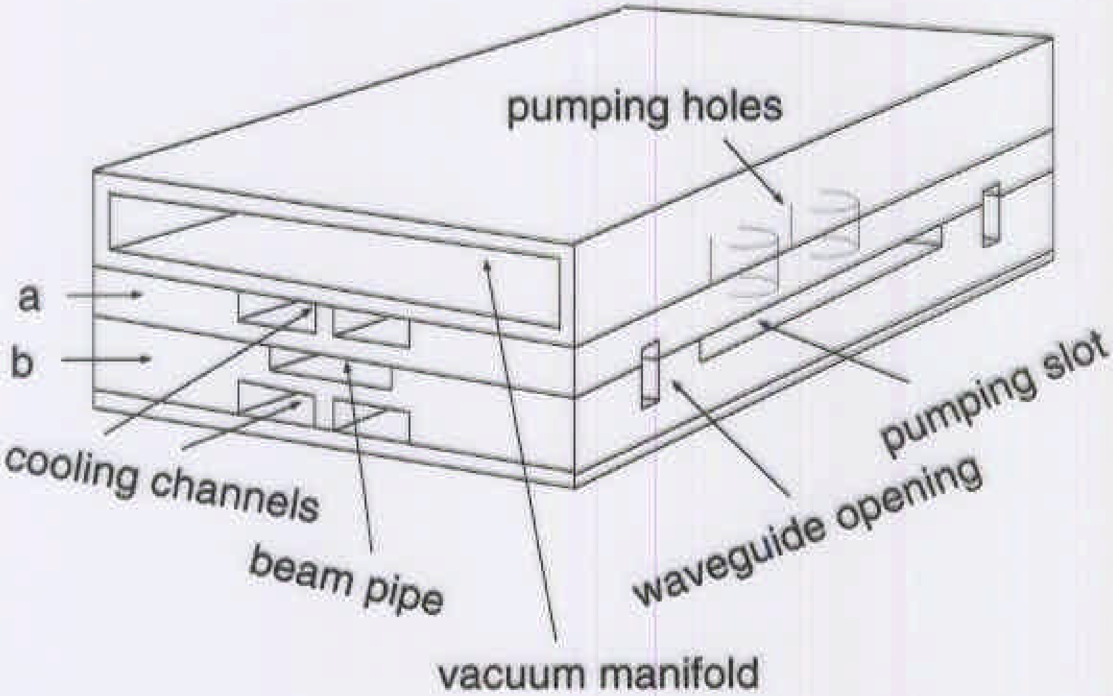
Sheet beam generation and transport

15 Ampere, 140 kV beam in 0.8x7.2mm channel

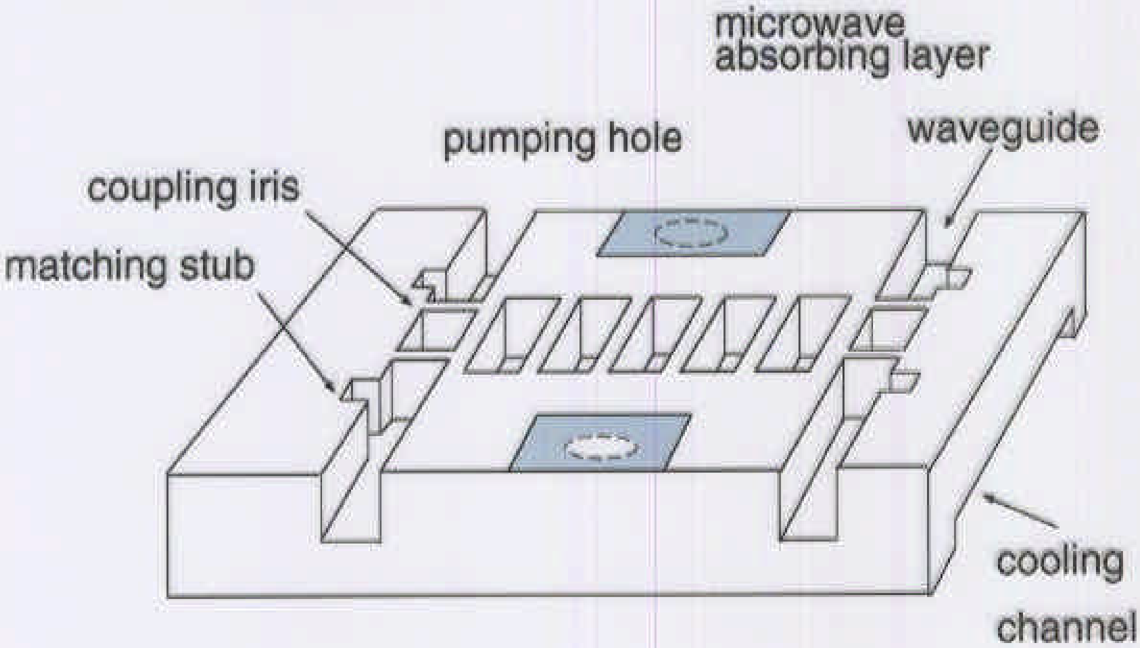
Tube instability, oscillation

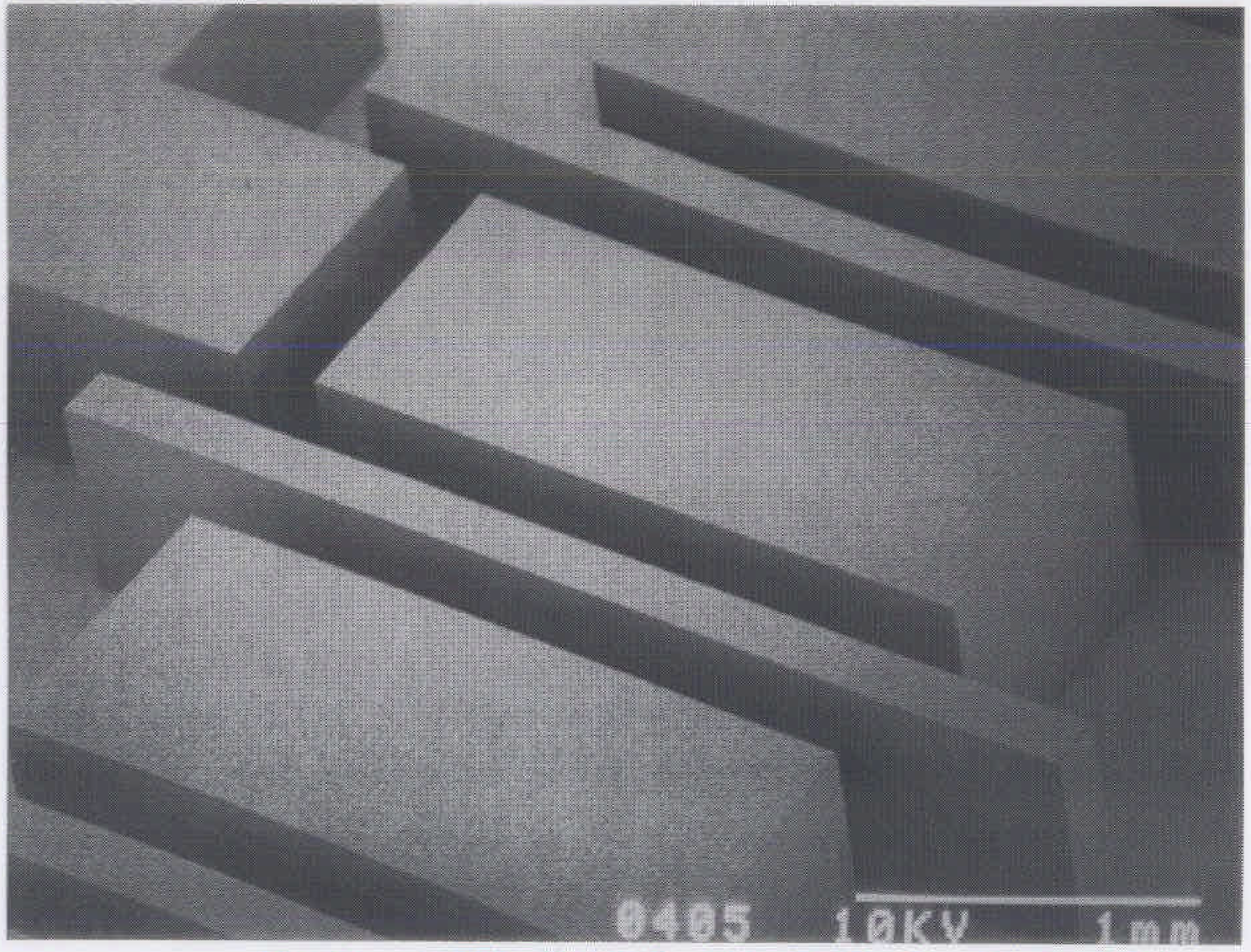
E. COLBY 3/29/00

FINAL ASSEMBLY

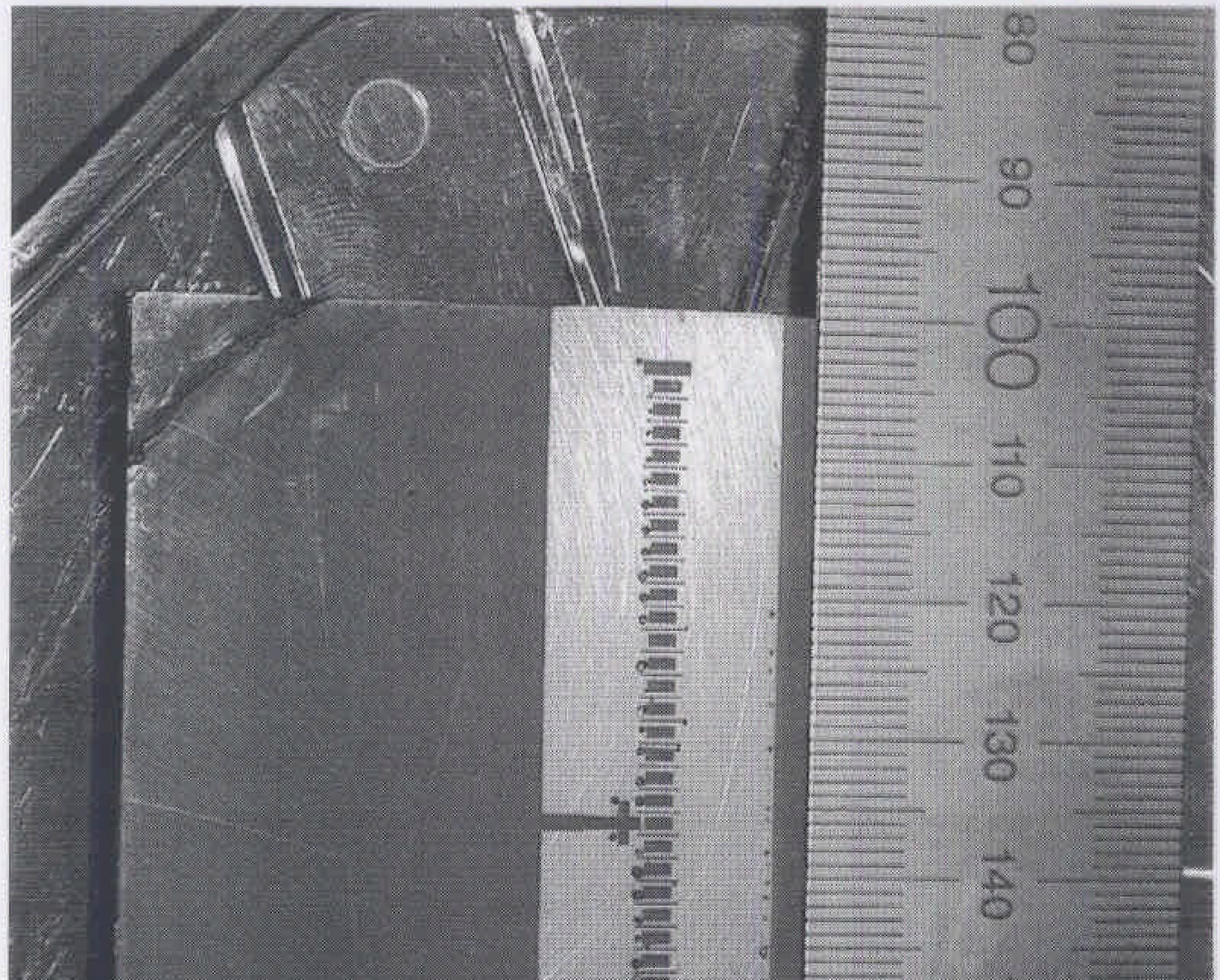


LAYER "A" SKETCH





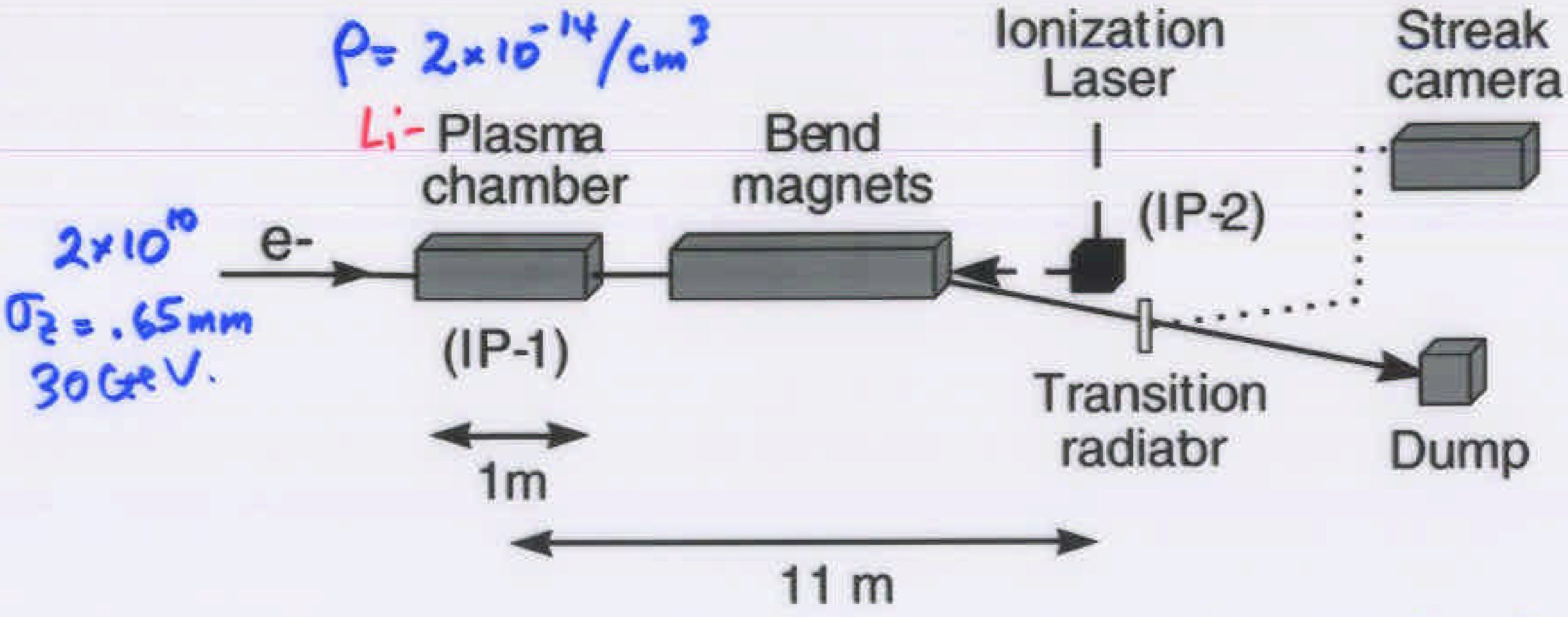
PMMA MASK FORMED BY EXPOSURE TO X-RAY


80
90
100
110
120
130
140
150
160
170
180

E-157 (EXP SUMMER '99) @ SLAC

PWFA – PLASMA-BASED WAKEFIELD ACCELERATION

Layout of SLAC-FFTB Plasma Wakefield Experiment



- STRONG TRANSVERSE FOCUSSING CREATED THRU PLASMA WAKE HAS BEEN SEEN. (~6000 T/m)
- WORK UNDER WAY TOWARDS DETECTING LONGITUDINAL FORCES (i.e. ACCELERATION)

3b. Laser Acceleration

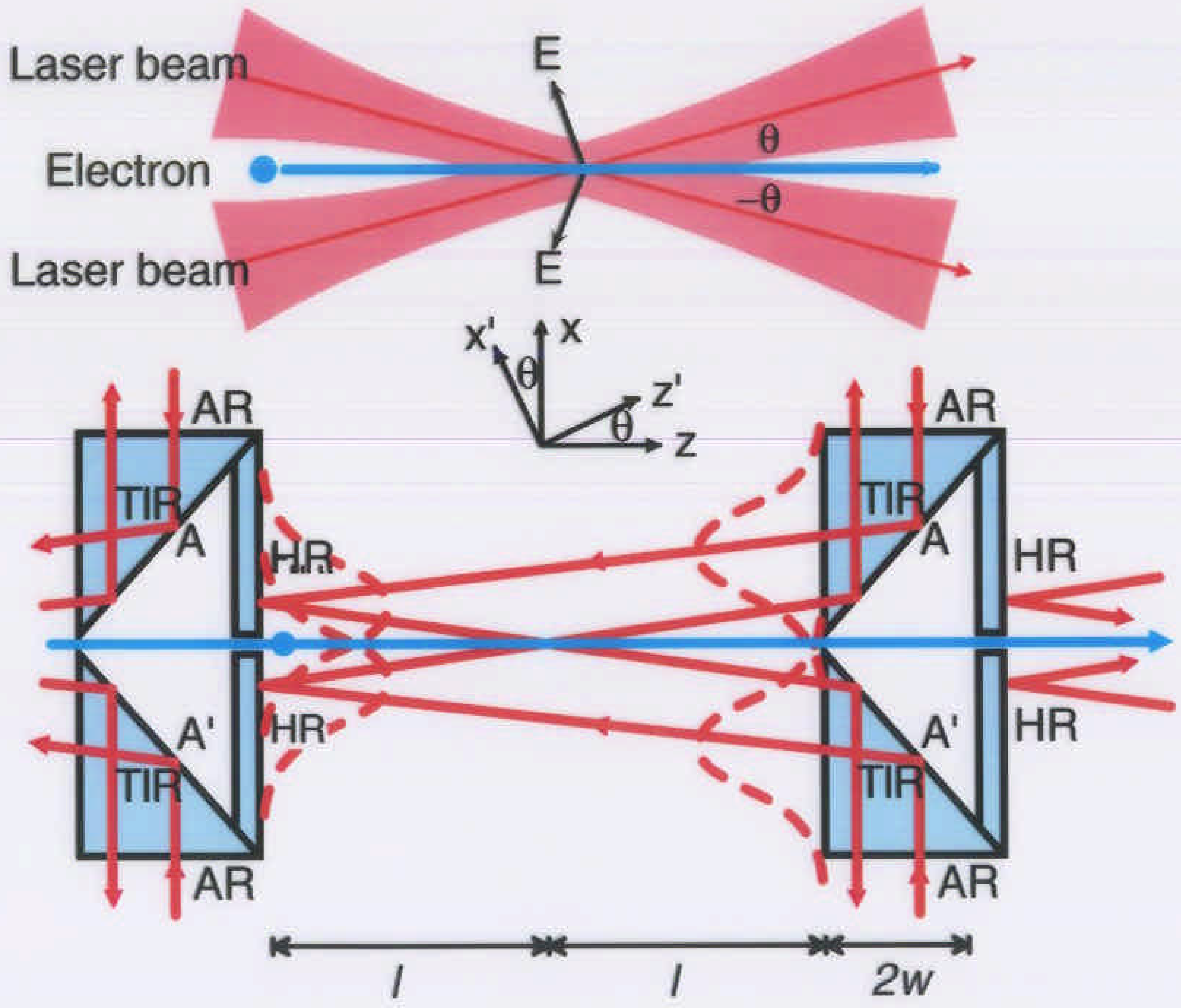
Lasers with $\lambda = 1 - 2$ nm

10^{19} W/cm² irradiance → 10 GV/m

Arrange two (or more) laser beams in a way to produce longitudinal electric field relative to the beam travel.

- LEAP Project (SLAC, Ginzon, HEPL)
  - Aim at demonstrate laser-driven electron acceleration in a dielectric structure in vacuum. Prep exp studies under way.

    1mJ/pulse Ti - Saphire laser


Laser beam
Electron
Laser beam
E
E
θ
−θ
x'
x
θ
z'
θ
z
AR
TIR
A
HR
A'
TIR
AR
HR
AR
TIR
A
HR
A'
HR
TIR
AR
l
l
2w

4. Conclusions / Observations

- R&D teams worldwide are making steady progress towards next-generation LCs at this stage of fundamental R&D.

- However, none of the next-generation LC schemes have cleared substantial portion of industralization issues associated with mass production of high-precision RF (and other) hardware components at this point.

- The break-through can occur, hopefully, through extension / expansion of existing test facilities (some may have to be new), which demonstrate the working of a fraction of the real-life RF system (and others, such as DR, collim., FF/IR...).

- A major amount of funding, resources and manpower are required. While being arduous, we should realize they are quite intellectually stimulating tasks.

- It is perhaps worth considering creating a more active network in the HEP community which strongly encourages the mobility of scientists and engineering (particularly, the young ones) across -

  - HEP research
  - Next-generation LC research
  - Basic and applied research in, e.g.
    W-band, Plasma...

Participation is the keyword,