Compact LInear Collider (CLIC)
and Higher Energy Linear Colliders

- Overview of schemes
  - for energies beyond upgrades of TESLA, NLC, JLC
  - using "conventional" techniques
  - for Advanced Concepts → talk by J. Wurtele → Friday
- Status and plans
- Collaboration & Cooperation
  EU, JA, RU, US (Int. LC Collaboration)

Basic motivation

- study e^+e^- ($\gamma\gamma$, $e\gamma$, e^-e^-) collider with
  $E_{cm} > E_{cm}(LHC)$ at constituent level
- <u>same</u> accel. principle up to the highest energies
  and extendible with the same technology
  → components produced in large series → cheap
- high accelerating field → compact facility
- simple layout → goal: one single tunnel
  with only passive elements

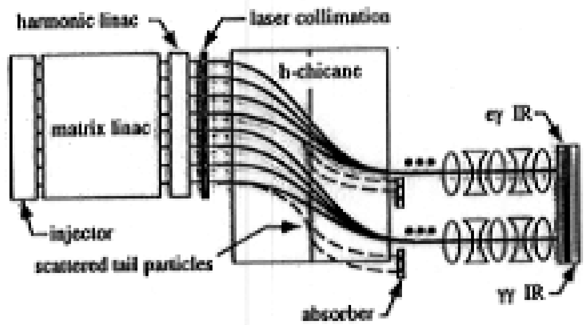
Schemes considered

- Matrix Linac oper. at 90 GHz — SLAC
- Two-Beam Acc. (CLIC) 30 GHz — CERN/LAL/SLAC/INFN....
- — " — (Relat. klystron) — LBL/LLNL

<u>High f_{rf}</u> required for <u>high gradient</u>

Compact 5 TeV e^+e^- Collider

D.H. Whittum & F. Zimmermann / SLAC



91 GHz

$L \sim n_b^2$

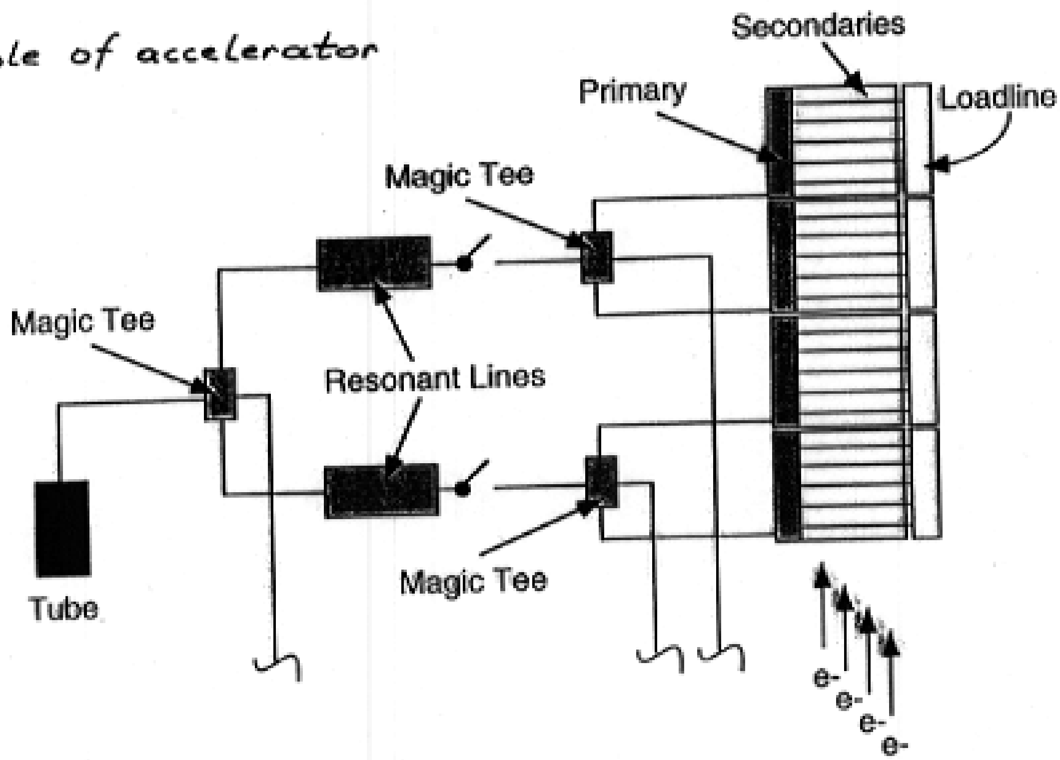
$L_{e^+e^-} = 10^{35}\ cm^{-2}s^{-1}$

$L_{\gamma\gamma} = 1.5 \times 10^{34}$ -"-

Table 1: Example Parameters for a Compact Collider.

parameter	W-Band example
center of mass energy	5 TeV
gradient	1 GeV/m
collision spot-size	1.8 nm
normalized emittance	10^{-7} m-rad
charge per linac bunch	60 pC
frequency	91.392 GHz
repetition frequency	120 Hz
main linac length	2.5 km
harmonic linac length	0.1 km

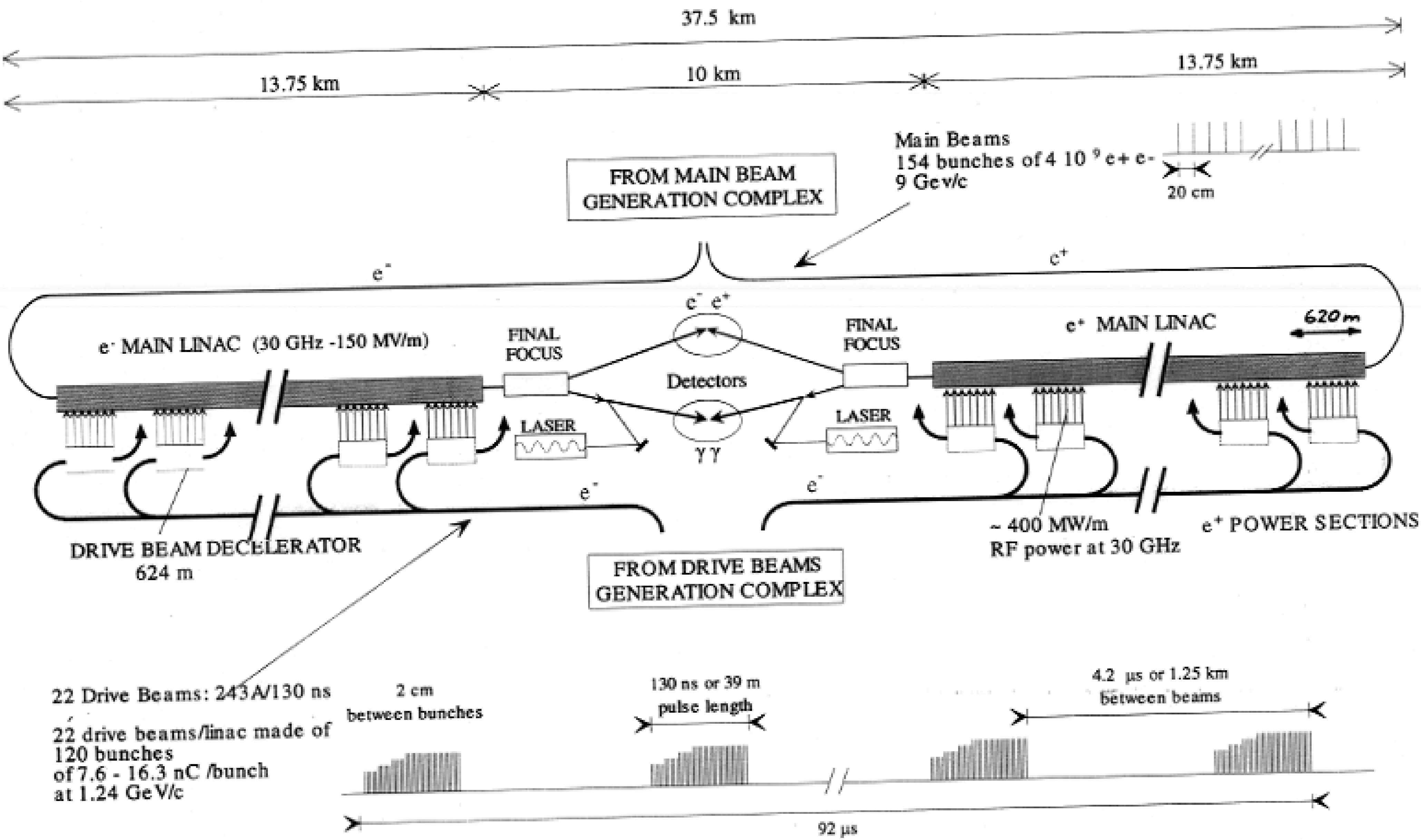
Principle of accelerator



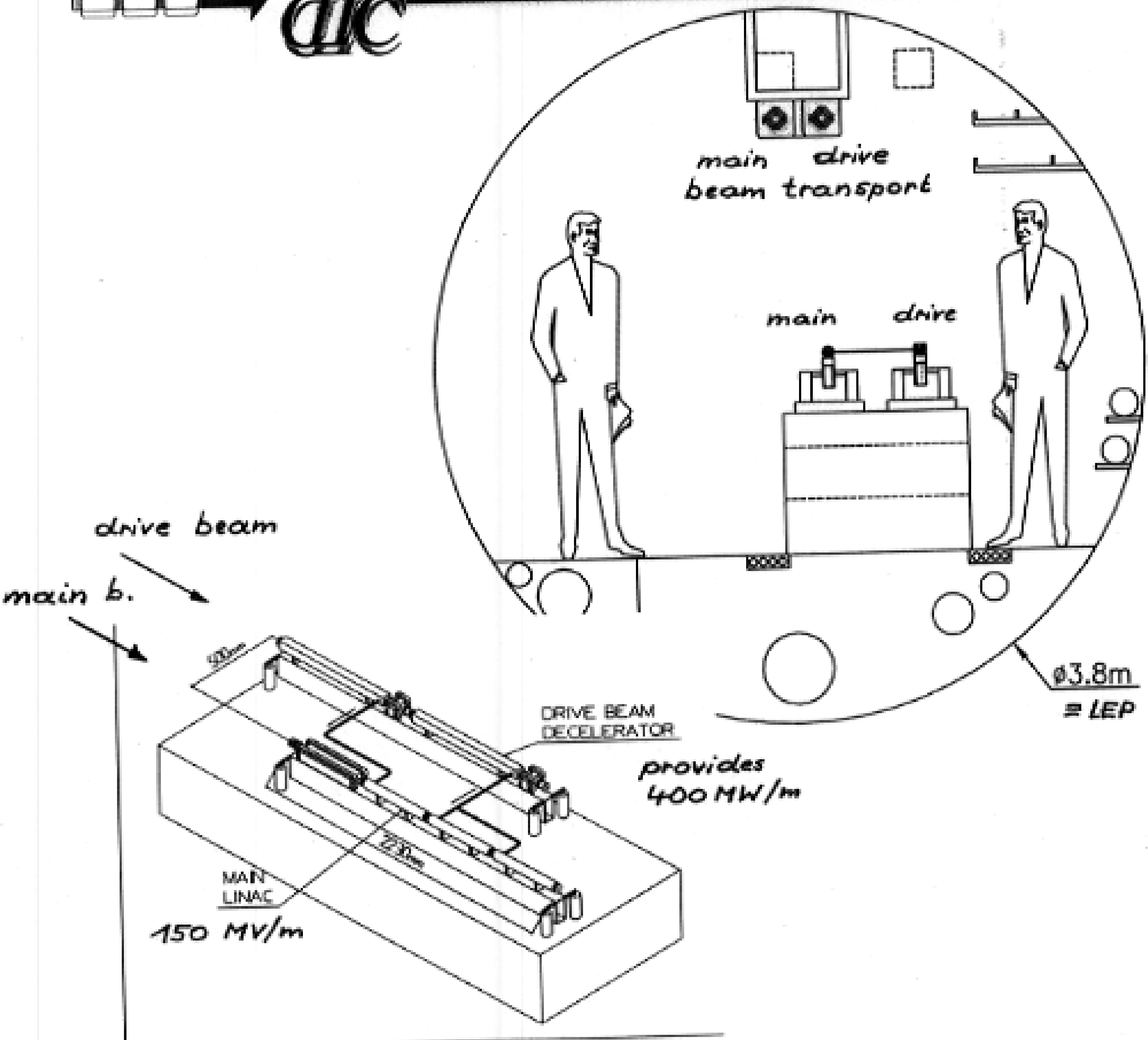
Overall Layout of the CLIC complex at 3 TeV c.m.

CERN (SLAC)

$f_{RF} = 30$ GHz



Tunnel Layout



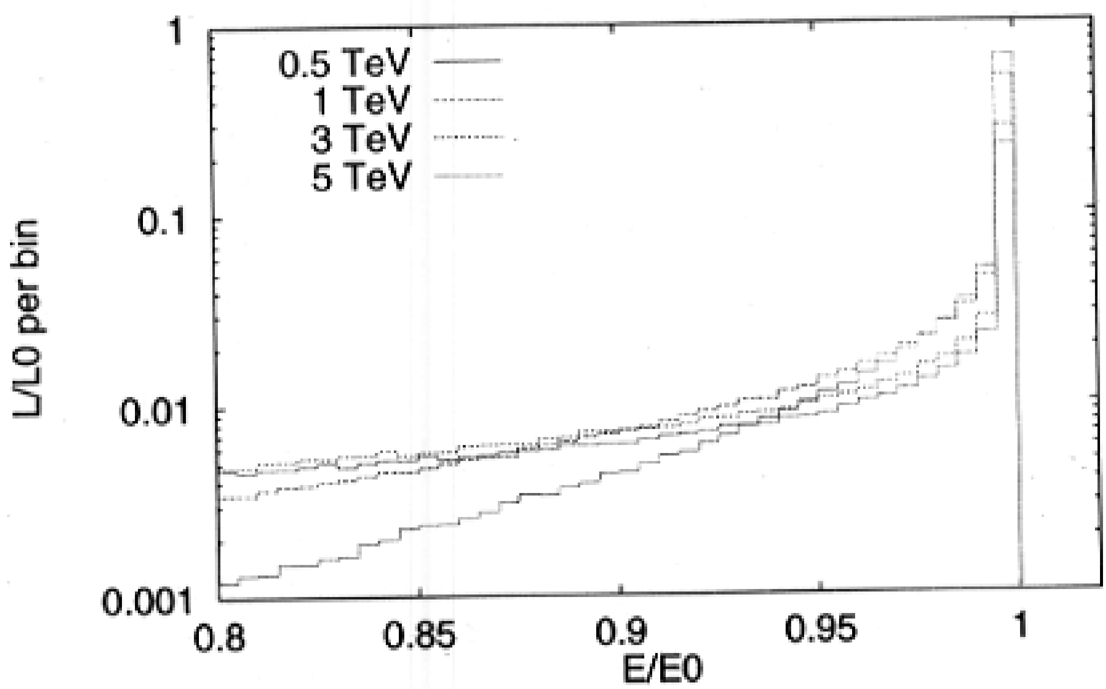
- No active RF components(no klystrons / modulators)
- Single small-diameter tunnel (3.8 m - same as LEP)

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
Lum. (1%$\Delta p/p$) ($10^{34}cm^{-1}s^{-1}$)	1.0	1.5	3.0	2.4
Mean energy loss (%)	4.4	11.2	31	37
Photons /electrons	0.7	1.1	2.3	3.2
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. (%)	40.1	40.1	40.1	40.1
AC to beam effic. (%)	9.8	9.8	9.8	8.5
AC power (MW)	100	151	302	290

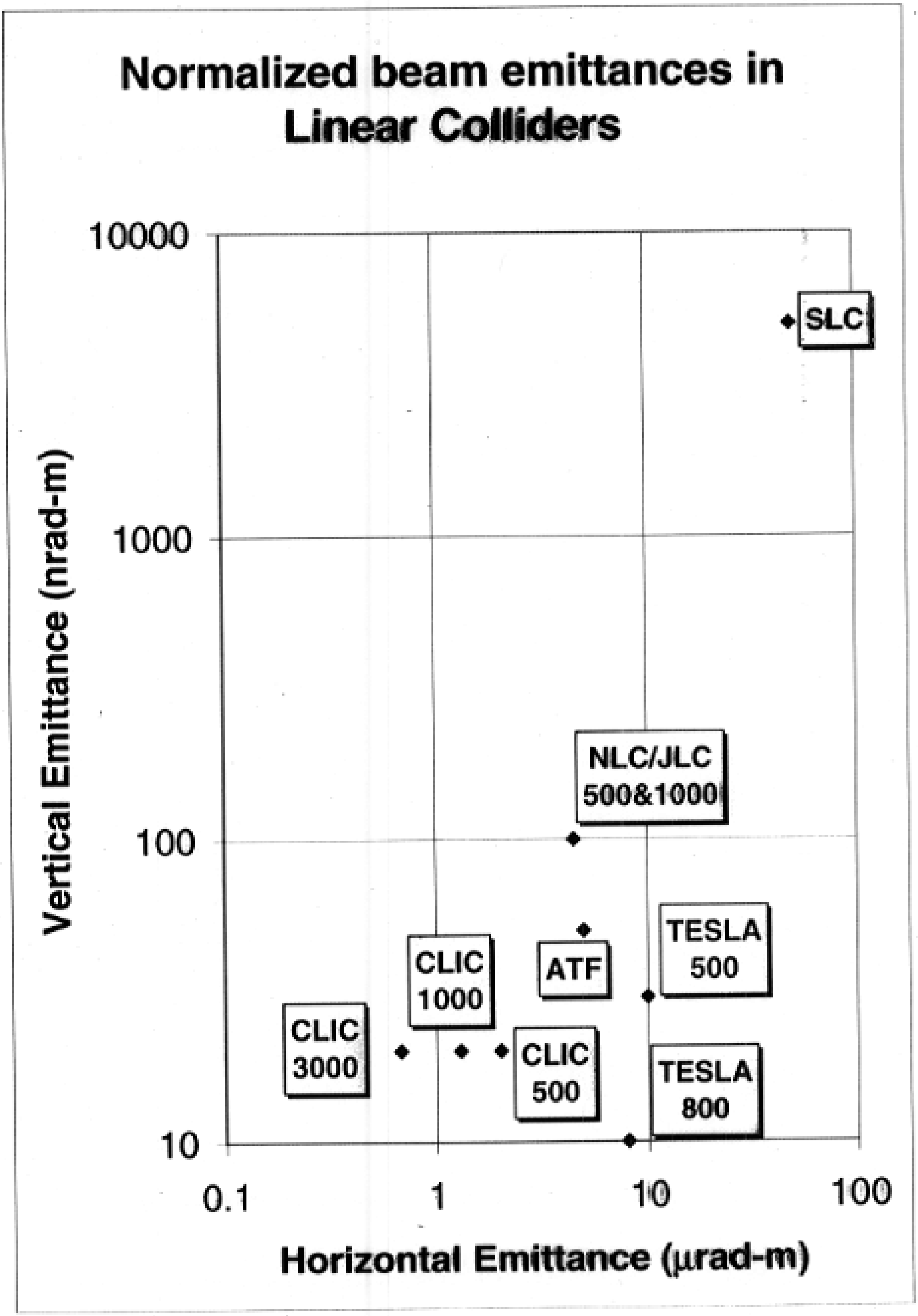
Luminosity spectrum

Might expect that mean energy loss parameter as high as 32% (3 TeV) would make luminosity spectrum unacceptable.



C.o.M. Energy (TeV)	0.5	1	3	5
L in 1% E_{cm}	71%	56%	30%	25%
L in 5% E_{cm}	87%	71%	42%	34%

Luminosity spectrum does not deteriorate dramatically with energy


Normalized beam emittances in
Linear Colliders
Vertical Emittance (nrad-m)
Horizontal Emittance (µrad-m)
10000
1000
100
10
0.1
1
10
100
SLC
NLC/JLC 500&1000
TESLA 500
TESLA 800
ATF
CLIC 3000
CLIC 1000
CLIC 500

Interaction Region Issues

Collimation, final focus, background, spent beam
Not yet solved, under study for CLIC ($3\,TeV = E_{cm}$)

- Collimation: by laser, non-linear resonances,
  liquid metal targets

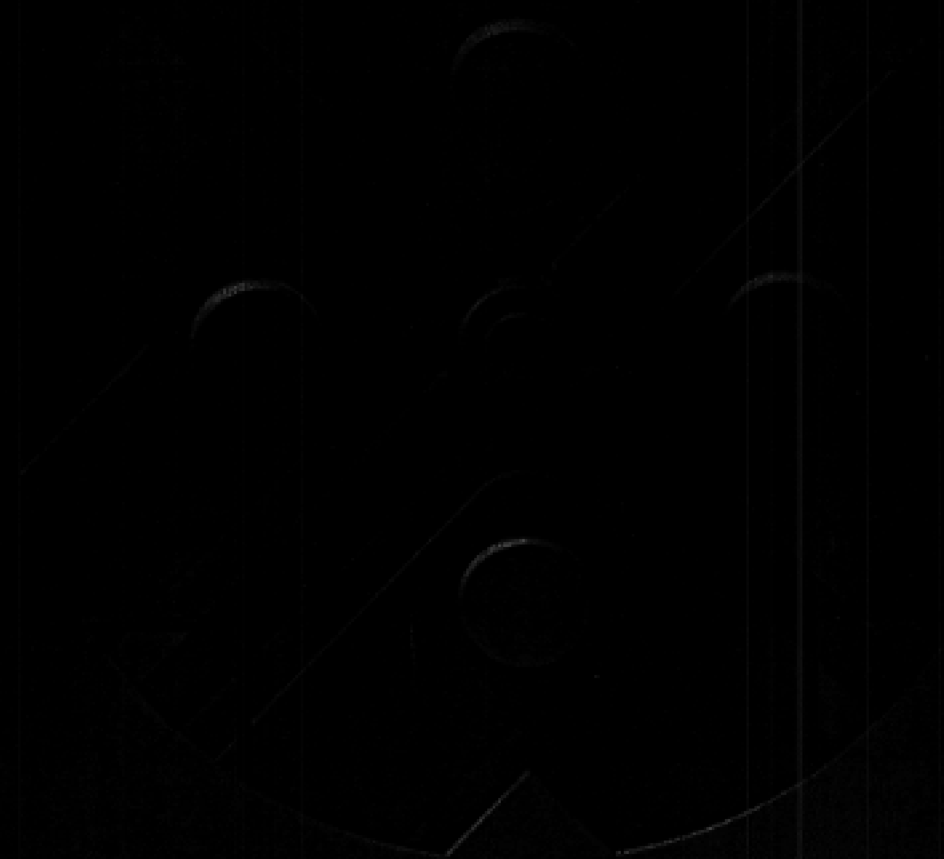
- Final focus: concern is length
  "conventional" FF $\ell \sim \gamma^2$
  e.g. $2\ell \cong 4\,km$ for NLC (1.5 TeV)

  possible remedies: lower $\Delta p/p$ at linac output
  lower chromaticity of final lens

- Background:
  - coherent e^+e^- pairs from γ (beamstrahlung)
    biggest challenge! confined to small angle
    at CLIC (3 TeV) of $N_b^e = 4.10^9$ particles in bunch
    $N_{pairs}^{coh} = 0.8.10^9$ pairs per bunch
    $\overline{P}_{pairs} = \underline{0.45}$ MW per side!
  - incoherent pairs from $\gamma\gamma$, $e\gamma$, ee
    $N_{pair}^{incoh} = 0.5 \times 10^6$ per bunch crossing

    assume $B = 4\,T$, $r_{Vertex} = 30\,mm$
    $N_{hits} = 0.5$ per bunch train (160 b)

Important: solutions must be stable against:
beam and component jitter, mis-steering of beam,
fluctuations in beam intensity



Cell of CLIC Accelerating Structure

TW, tapered, damped, 2π/3 constant gradient

[illegible] (150 cells)

scaled to 15 GHz for test in ASSET at SLAC

[illegible]

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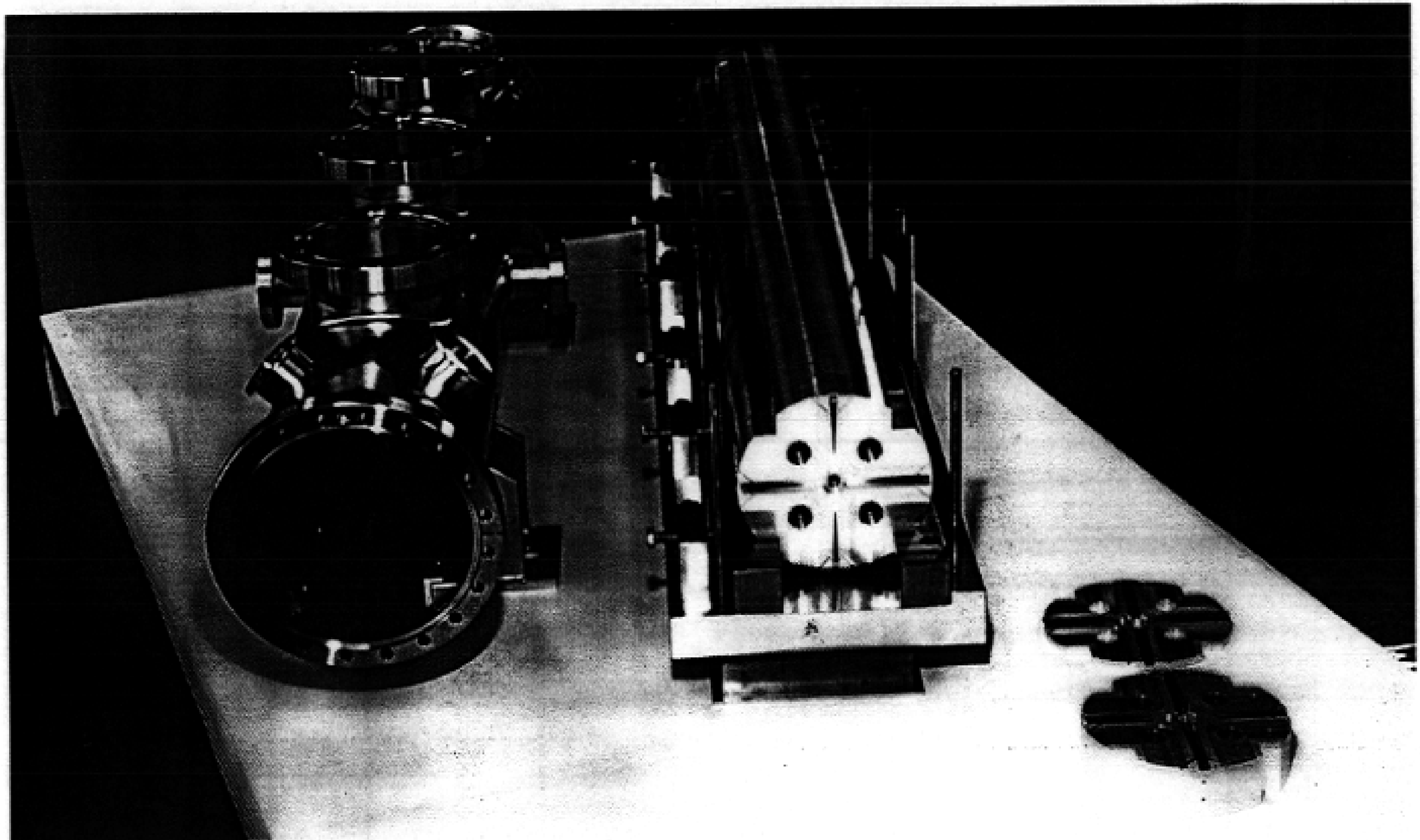


W. Wuensch

CLIC Accelerating Structure 150 cells
TW, tapered, damped
Scaled to 15 GHz for ASSET test at SLAC

Planar Accelerating Structures

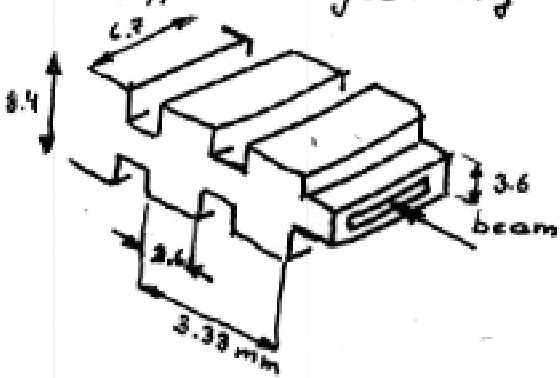
High electric field → high f_{rf} → best choice: planar geometry

Considered by TU Berlin and SLAC

Produced

- cold model for tests of fabrication methods at 30 & 90 GHz
- engineered prototype at 30 GHz (TU Berlin) for power tests in CLIC Test Facility (CTF2):

"muffin-tin" geometry



37 cells (final ≤ 375 cells)

$2\pi/3$ TW

$r/Q_0 = 23\ k\Omega/m$

$Q_0 = 4420$

$P = 80$ MW

$\Delta t_{pulse} = 4$ ns

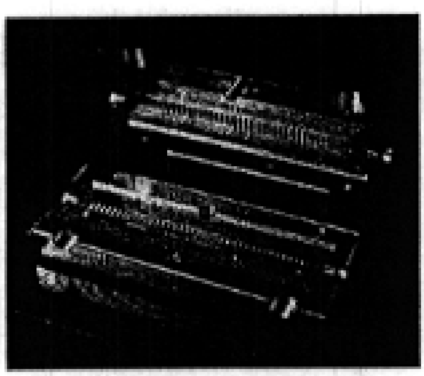


Figure 2. Manufactured 37-cell structure.

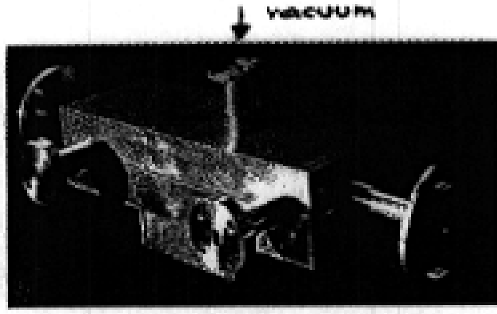
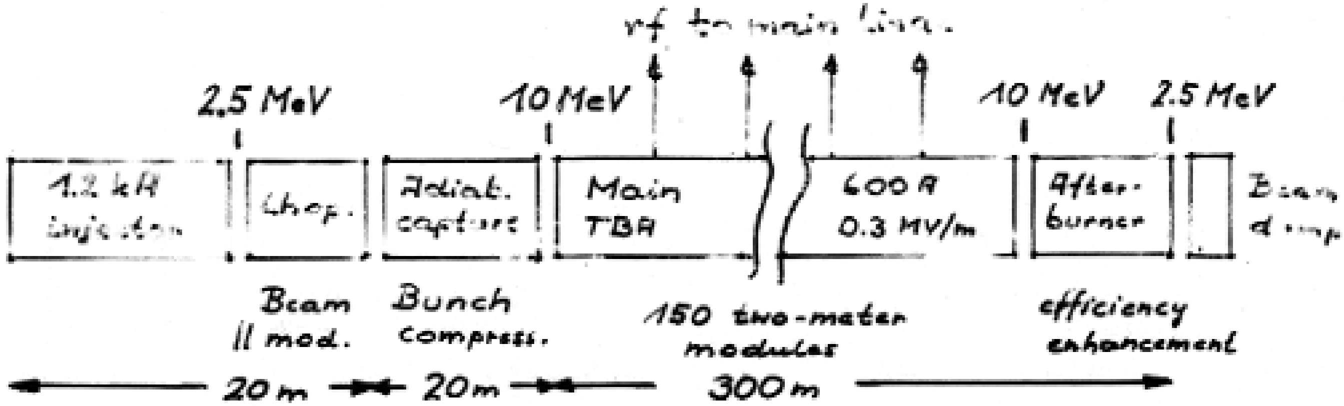


Figure 3. Manufactured structure with RF-, beam pipe- and vacuum-flanges.

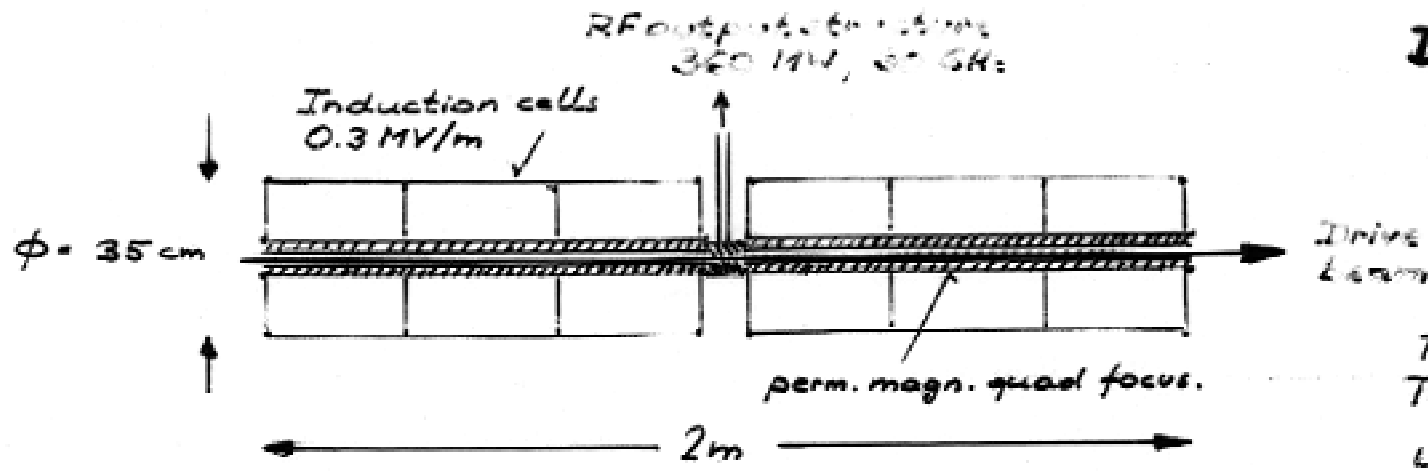
Relativistic Klystron

for Two-Beam Accelerator (LBNL, LLNL)
Prototype work at LBNL (6y R&D progr.)

RK-unit



Drive-beam module



RTA
Test facility at LBNL
4 MeV drive beam
unit length 26 m

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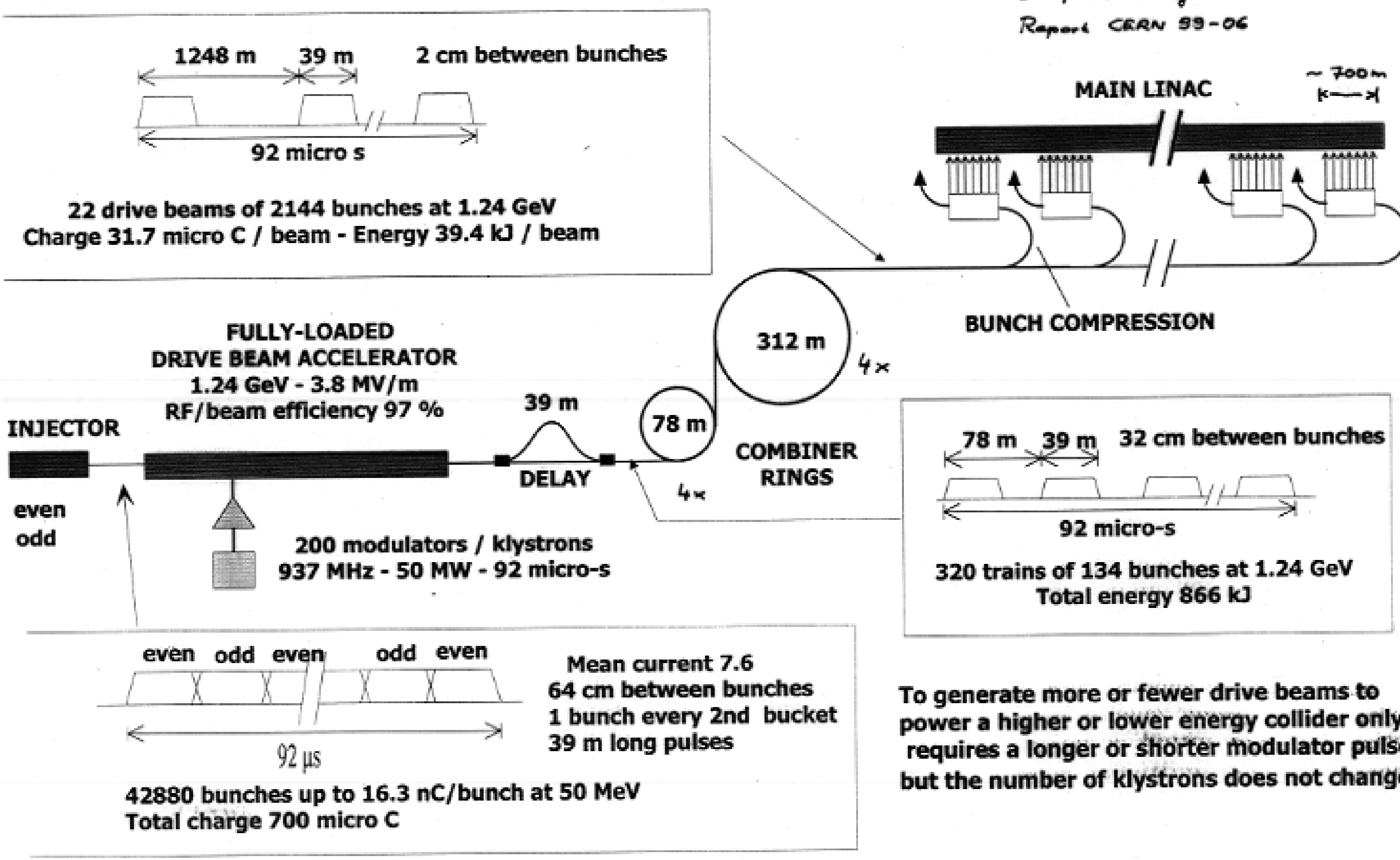
CLIC RF POWER SOURCE FOR 3 TeV COLLIDER

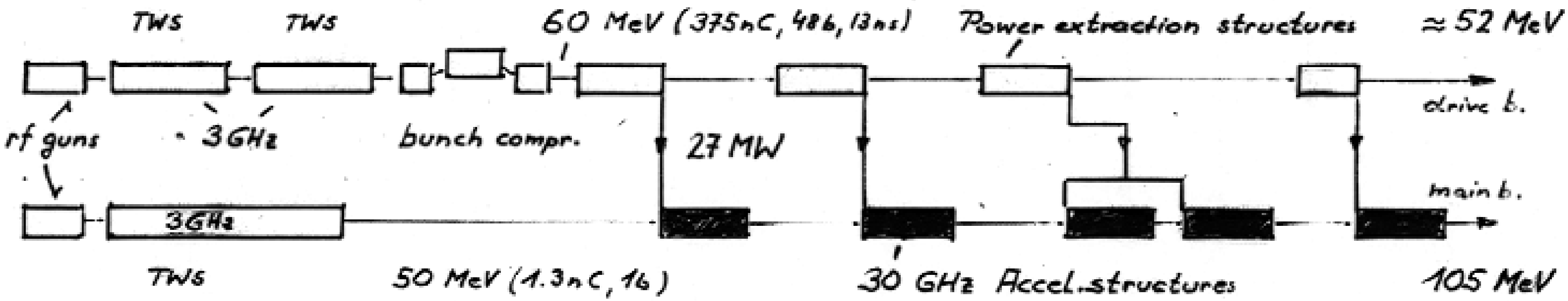
see forthcoming Report CERN 99-06



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 2 (CTF2)

(status mid 1999)



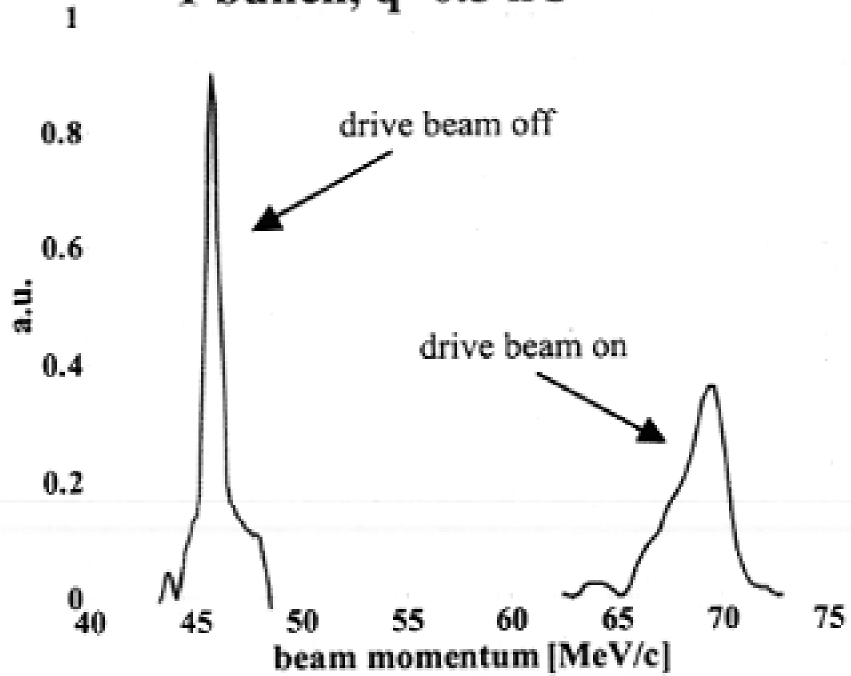
Tests 1996 – 2000	done	
– Feasibility of Two-Beam Acceleration	✓	
– Fully engineered CLIC test modules	✓	
– Drive beam (not final) generation/transport	✓	(with LAL, Sweden)
– Active alignment system in accel. environment	✓	
– Study ΔE by coherent synchrotron radiation	in progress	(with DESY)

- Use longer power extr. structure to increase $E_a \rightarrow 150$ MV/m
- Test GaAs photocathode (in situ activation) (with SLAC)
- Test further "muffin-tin" accelerator structures (with TU Berlin)
- etc.

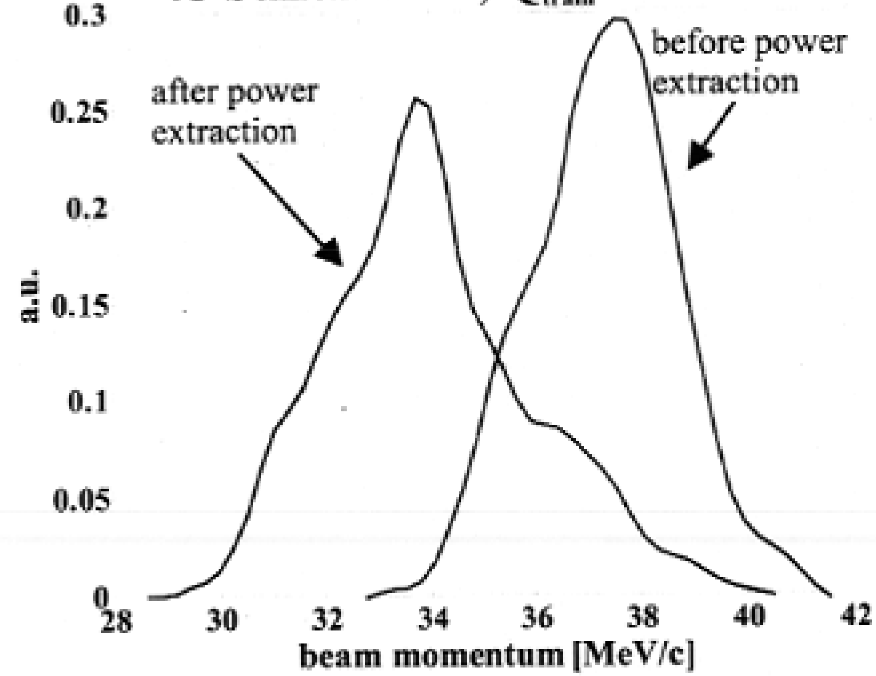
two beam acceleration at 30 GHz

CTF2

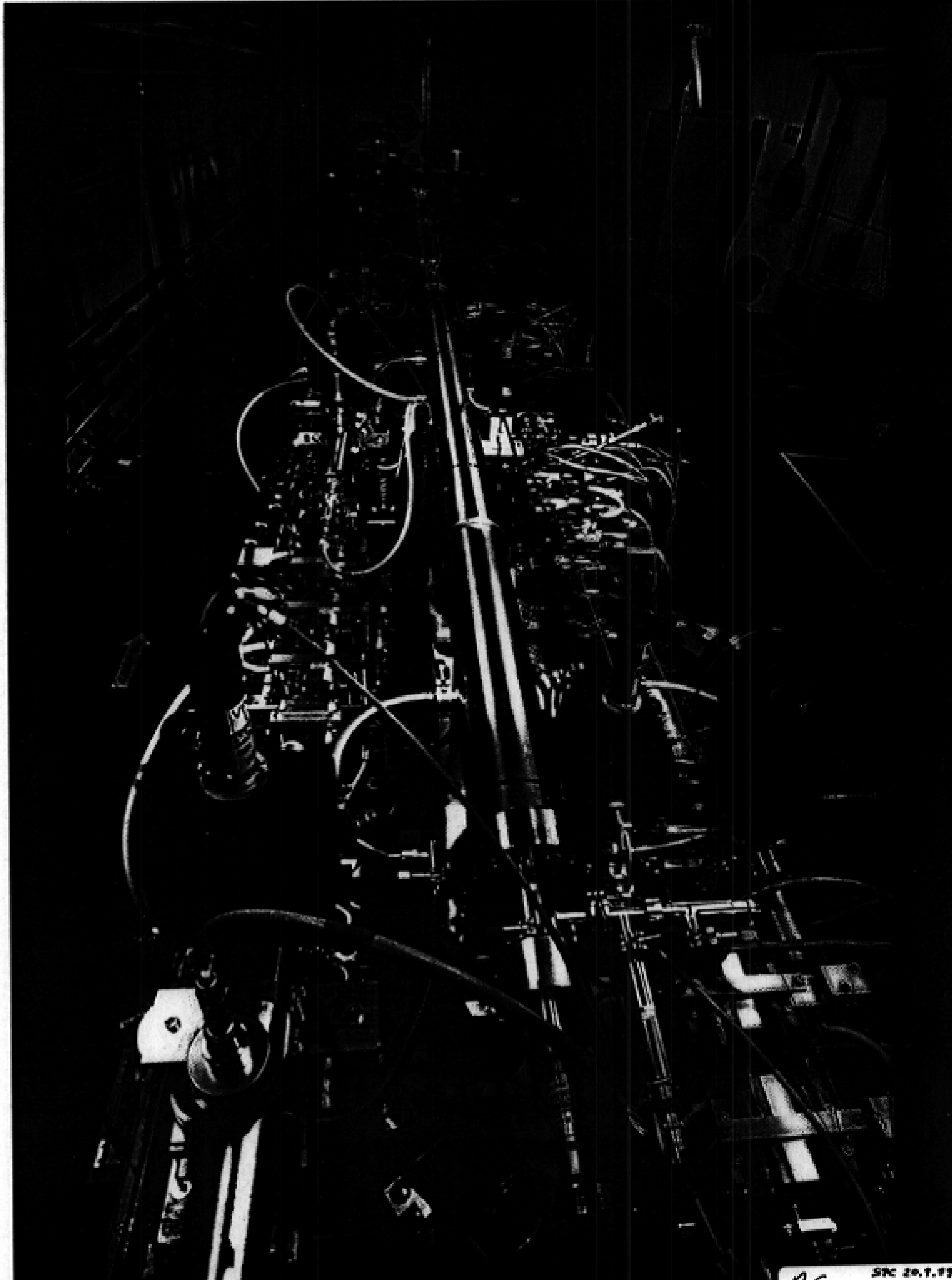
acceleration of main beam
1 bunch, q=0.5 nC



deceleration of drive beam
48 bunch train, Q_{train}=400 nC



2 accelerating structures fed by
2 transfer structures



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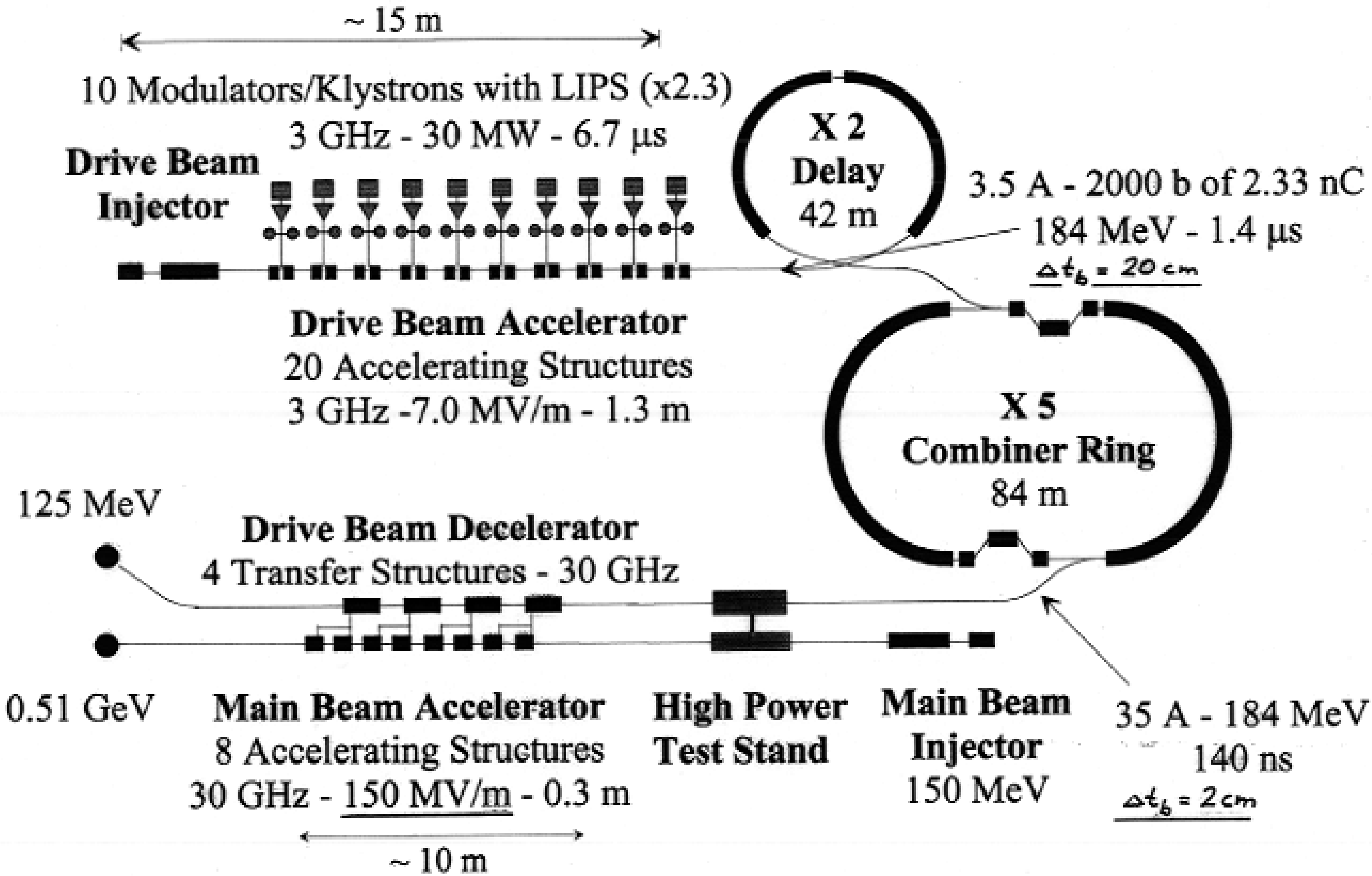
CLIC TEST FACILITY - CTF 3 - Nominal

Test of Drive Beam Generation, Acceleration & RF Multiplication by a factor 10

see CLIC note 402



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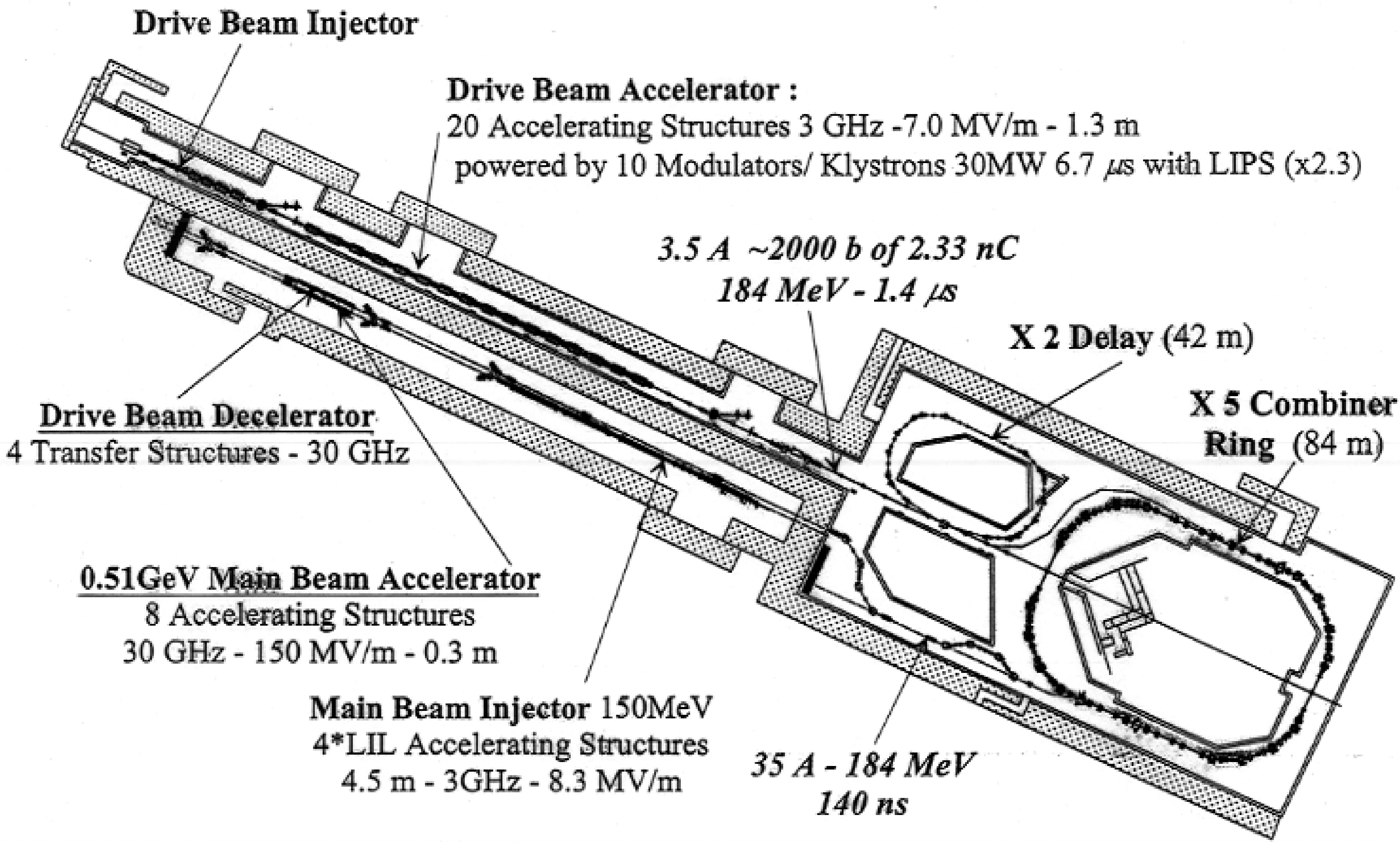

Figure 9 : A possible housing of the CLIC Test Facility (CTF3) in the LEP Pre-injector building

from CLIC note 402

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Tests with CTF3 and CLIC1

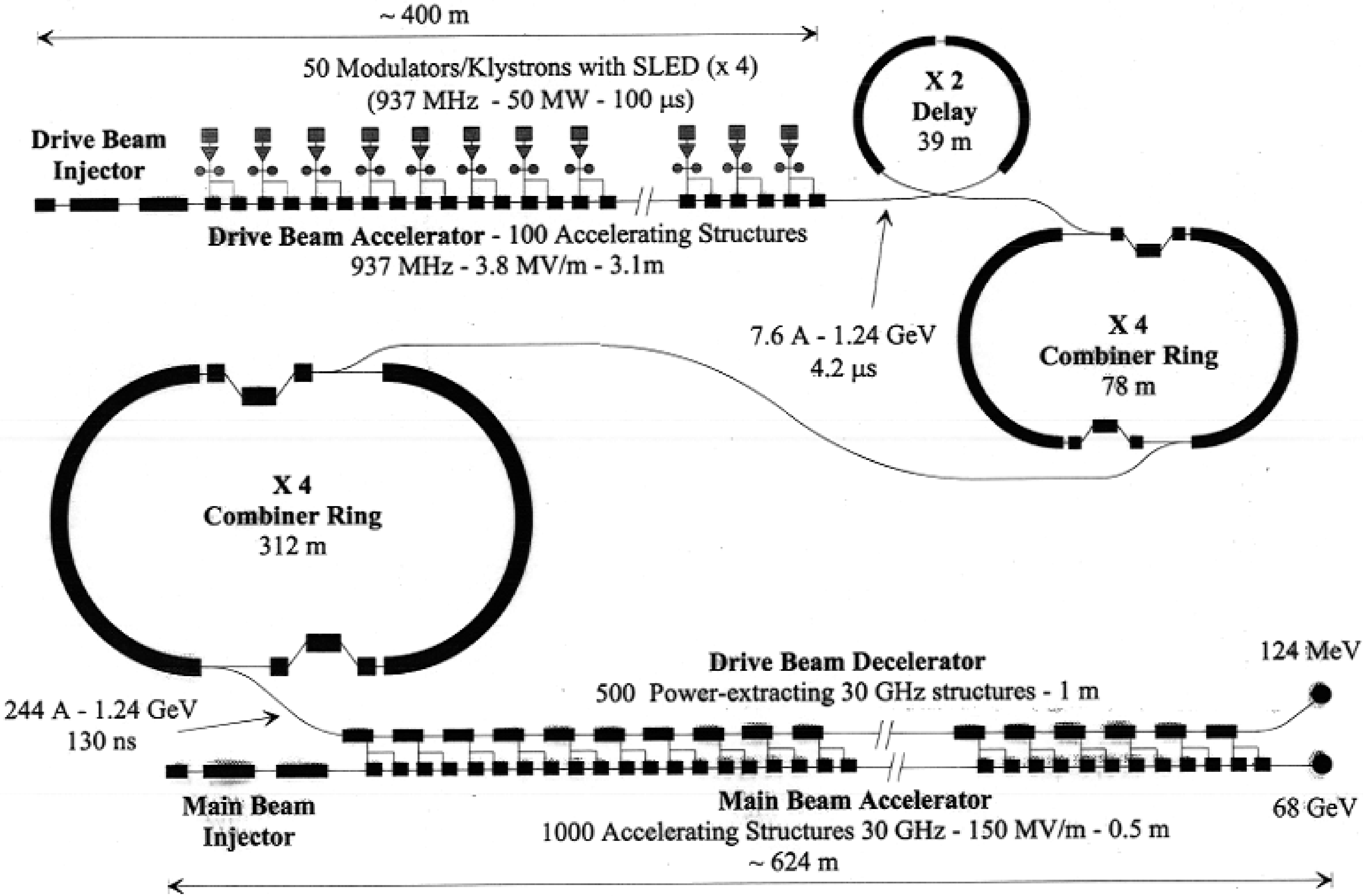
- **CTF3** (complete in 2004, 2005)

- first demonstration of "frequency multiplication" and pulse compression of drive beam 10x (CLIC 32x)
- operation of fully-loaded linac and combiner rings
- measurement of power efficiencies
- CLIC modules working at nominal E_{ac} and P_{rf} (150 MV/m for 140ns), System integration and pre-alignment ± 5μm
- beam loading compensation in 30 GHz accel. structures

- **CLIC 1**

- main beam accelerated to 68 GeV over 624 m (450m active) → beam stability, beam-based trajectory correction, ε-preservation
- drive beam stability during deceleration 1.24 GeV → 0.13 GeV trajectory control with large ΔE/E
- generation of one nominal drive pulse with beam train compression 32x
- validate beam loss management and hardware protection

CLIC 1 - Test of 1 Drive Beam of full energy



Conclusions

- Reasonable progress
  - key hardware
  - calculations & simulations
- Further work
  - rf hardware with design performanc
  - Test facilities with parameters → design values
  - Design Interaction point (collimation, final focus)
- Good collaboration and efficient mutual help between labs and institutes active in this field

see Linear Collider Workshop
Lab. Naz. Frascati 21-26 Oct. 1999