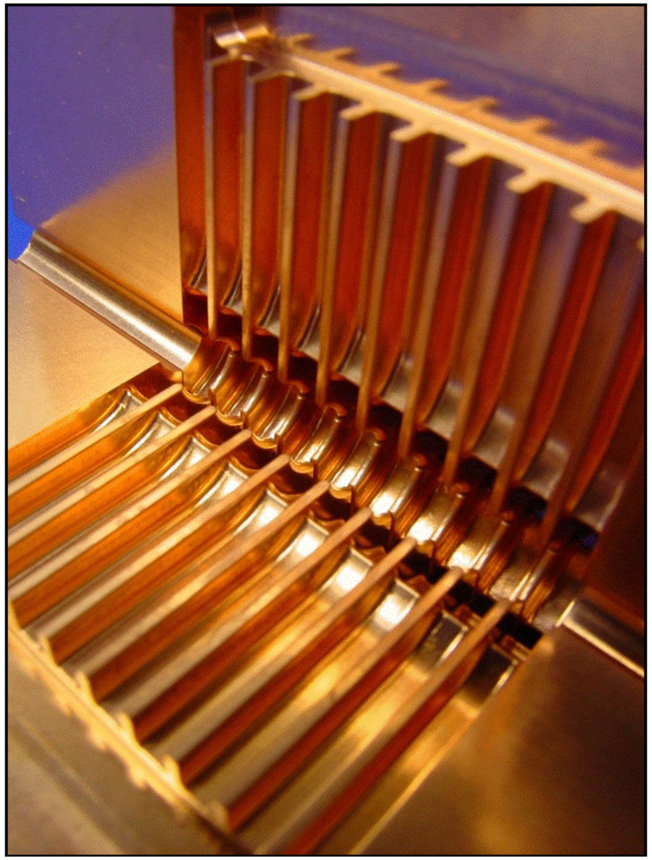
FrontierScience 2005

R&D on Multi-TeV Linear Collider

Status and perspectives

Hans Braun on behalf of Roberto Corsini for

The Compact Linear Collider Study Group



http://clic-study.web.cern.ch/CLIC-Study/

I give this talk on behalf of Roberto Corsini who had a serious scheduling problem…

… caused by late delivery of

TALK OUTLINE

- The CLIC Multi-TeV Linear Collider scheme – brief introduction
- Main challenges
- What has been achieved so far
- What remains to be done

Will focus on CTF 3 – the test facility to address the main key issues

CLIC aim:

Develop technology for e^-/e^+ collider with E_{CM}= 1 -5 TeV

Physics motivation:

"Physics at the CLIC Multi-TeV Linear Collider: report of the CLIC Physics Working Group", CERN report 2004-5

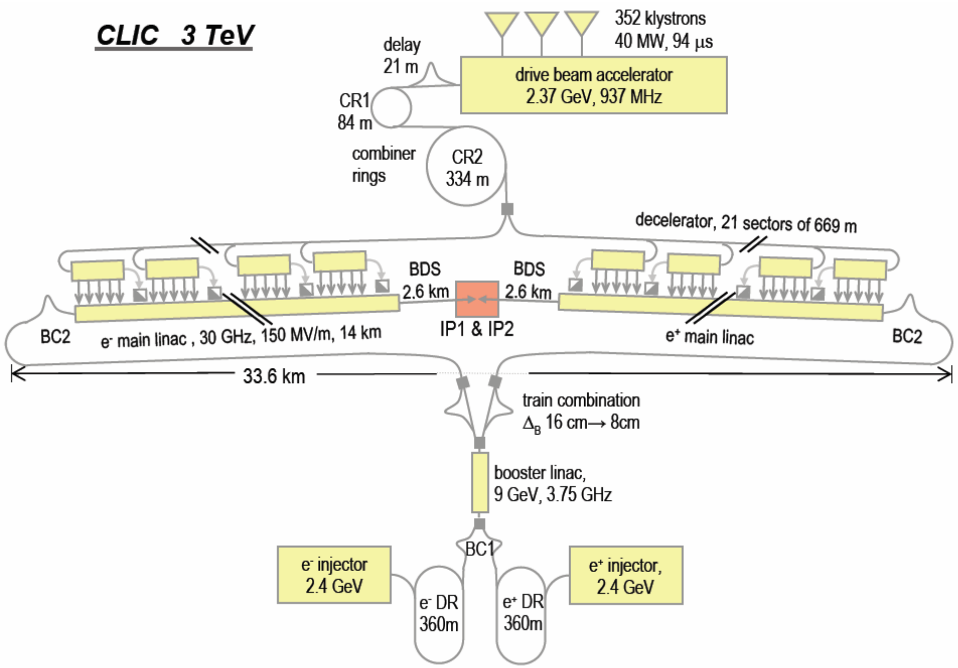
Present mandate:

<u>Demonstrate all key feasibility issues by 2010</u>

WORLD WIDE CLIC COLLABORATION

Ankara University (Turkey):	CTF3 beam studies & operation
Berlin Tech. University (Germany):	Structure simulations GdfidL
BINP (Russia):	CTF3 magnets development & construction
CERN:	Study coordination, structures devel., CTF3 construction/commissioning
CIEMAT (Spain):	CTF3 septa and kickers, correctors, power extraction structures
DAPNIA/Saclay (France):	CTF3 probe beam injector
Finnish Industry (Finland):	Sponsorship of mechanical engineer
INFN / LNF (Italy):	CTF3 delay loop, transfer lines & RF deflectors, ring vacuum chambers
JINR & IAP (Russia):	Surface heating tests of 30 GHz structures
KEK (Japan):	Low emittance beams in ATF
LAL/Orsay (France):	Electron guns and pre-buncher cavities for CTF3
LAPP/ESIA (France):	Stabilization studies, CTF3 beam position monitors
LLBL/LBL (USA):	Laser-wire studies
North-West. Univ. Illinois (USA):	Beam loss studies & CTF3 equipment
RAL (England):	Lasers for CTF3 and CLIC photo-injectors
SLAC (USA):	High Gradient Structure testing, structure design, CTF3 injector design
Uppsala University (Sweden):	Beam monitoring systems for CTF3

BASIC FEATURES OF CLIC



OVERALL LAYOUT OF CLIC
FOR A CENTER-OF-MASS ENERGY OF 3 TeV

- High acceleration gradient (150 MV/m)

  - "Compact" collider - overall length □ 40 km
  - Normal conducting accelerating structures
  - High acceleration frequency (30 GHz)

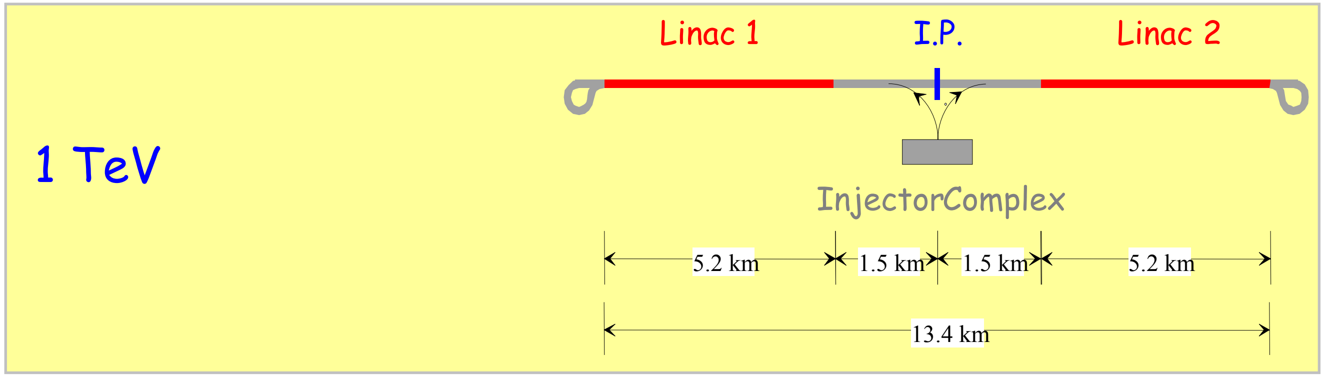
- Two-Beam Acceleration Scheme

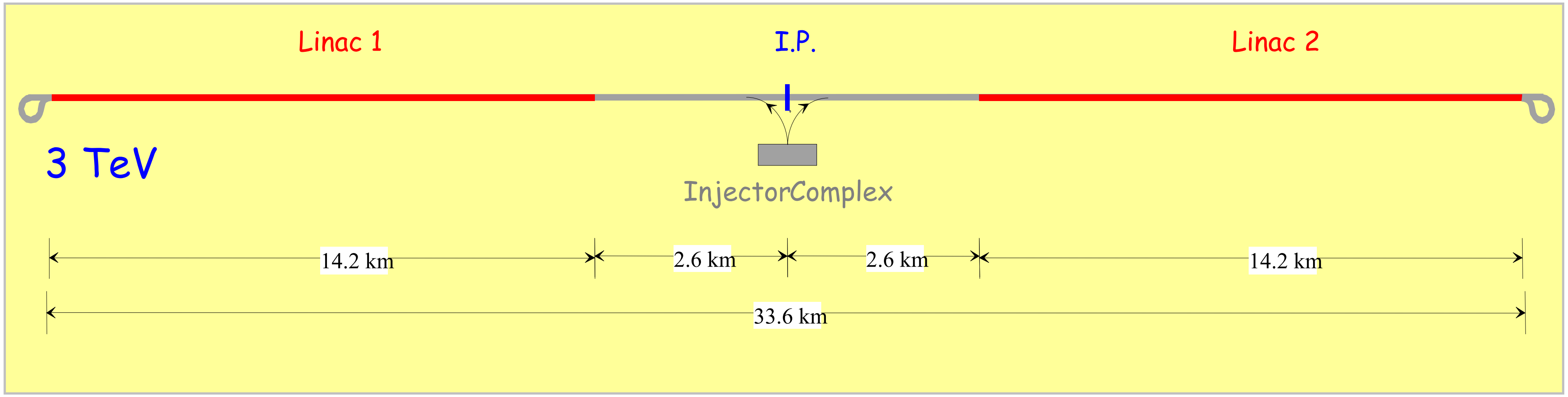
  - Capable to reach high frequency
  - Cost-effective & efficient (~ 10% overall)
  - Simple tunnel, no active elements

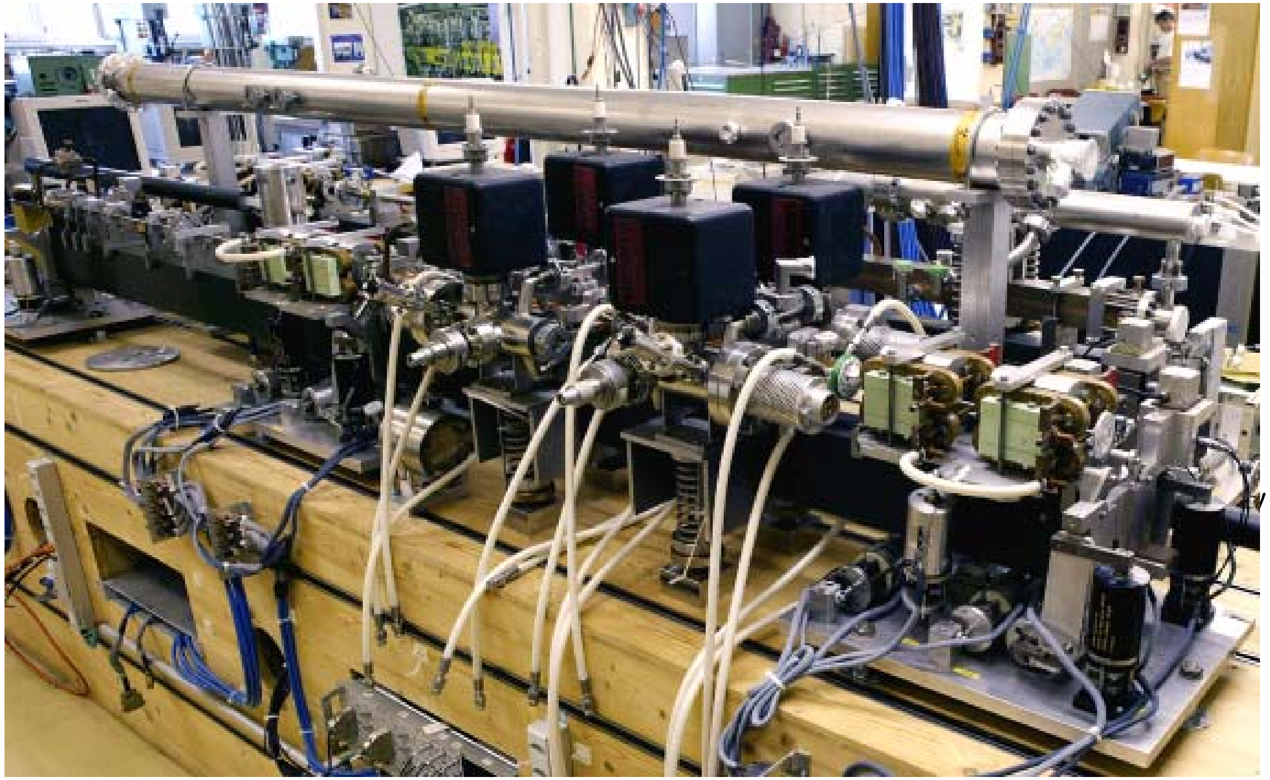
- Central injector complex

  - "Modular" design, can be built in stages

Phased construction of CLIC



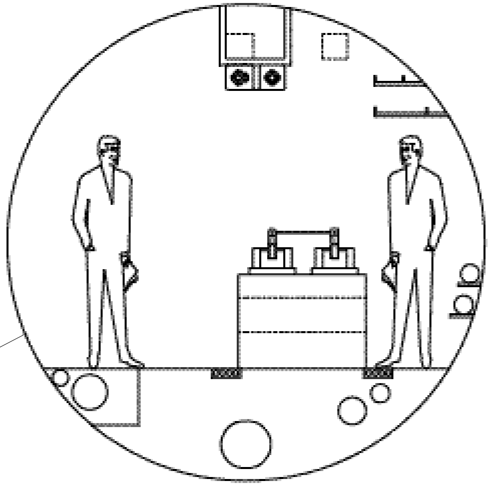




CLIC MODULE

(12000 modules at 3 TeV)

CLIC TUNNEL CROSS-SECTION



3.8 m diameter

CLIC TWO-BEAM SCHEME

LUMINOSITY SCALING IN A LINEAR COLLIDER

$$L = \frac{k_b N_b^2 f_{rep}}{4\pi U_{cm} \sigma_x^* \sigma_y^*} \propto \frac{\delta_B^{1/2} \times \eta_{beam}^{AC} \times P_{AC}}{U_{cm} \varepsilon_{ny}^{*\,1/2}}$$

- energy loss by beamstrahlung ($\delta_B^{1/2}$)
- wall-plug to beam efficiency (η_{beam}^{AC})
- wall-plug power (P_{AC})
- center-of-mass energy (U_{cm})
- Vertical emittance (ε_{ny}^*)

- Vertical beam emittance at I.P. as small as possible
- Wall-plug to beam efficiency as high as possible

CLIC MAIN PARAMETERS at 3 TeV

Center of mass energy	E_{cm}	3000	GeV
Main Linac RF Frequency	f_{RF}	30	GHz
Luminosity	L	6.5	10^{34} cm^{-2} s^{-1}
Luminosity (in 1% of energy)	$L_{99\%}$	3.3	10^{34} cm^{-2} s^{-1}
Linac repetition rate	f_{rep}	150	Hz
No. of particles / bunch	N_b	2.56	10^9
No. of bunches / pulse	k_b	220	
Bunch separation	Δt_b	0.267 (8 periods)	ns
Bunch train length	τ_{train}	58.4	ns
Beam power / beam	P_b	20.4	MW
Unloaded / loaded gradient	$G_{unl/l}$	172 / 150	MV/m
Overall two linac length	l_{linac}	28	km
Total beam delivery length	l_{BD}	2 x 2.6	km
Proposed site length	l_{tot}	33.2	km
Total site AC power	P_{tot}	418	MW
Total main beam power at IP	P_{Beam}	40.6	MW

THE CLIC CHALLENGES

COMMON TO MULTI-TEV LINEAR COLLIDERS

- Accelerating gradient
- Generation and preservation of ultra-low emittance beams
- Beam Delivery & IP issues

SPECIFIC TO THE CLIC TECHNOLOGY

- 30 GHz components
- Efficient RF power production by Two Beam Acceleration

addressed in CTF3

THE CLIC TECHNOLOGY-RELATED KEY ISSUES AS POINTED OUT BY ILC-TRC 2003

Covered by CTF3

R1: Feasibility

- R1.2: Validation of drive beam generation scheme with fully loaded linac operation
- R1.1: Test of damped accelerating structure at design gradient and pulse length
- R1.3: Design and test of damped ON/OFF power extraction structure

R2: Design finalization

- R2.1: Developments of structures with hard-breaking materials (W, Mo…)
- R2.2: Validation of stability and losses of DB decelerator; Design of machine protection system
- R2.3: Test of relevant linac sub-unit with beam
- R2.4: Validation of drive beam 40 MW, 937 MHz Multi-Beam Klystron with long RF pulse *
- R2.5: Effects of coherent synchrotron radiation in bunch compressors
- R2.6: Design of an extraction line for 3 TeV c.m.

Covered by EUROTeV

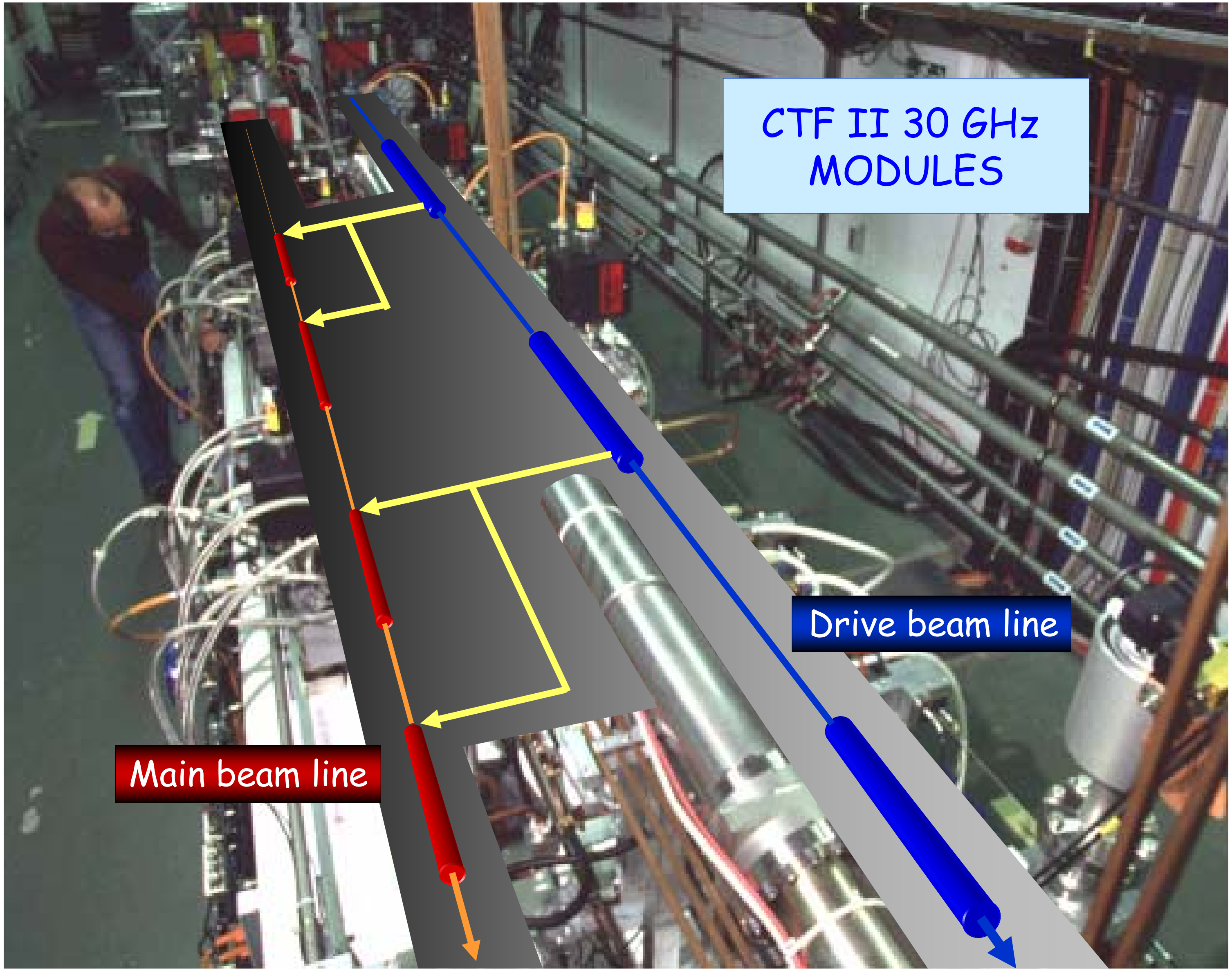
** Feasibility study done – need development by industry.*
N.B.: Drive beam acc. structure parameters can be adapted to other klystron power levels

WHAT HAS ALREADY BEEN ACHIEVED:

CLIC TEST FACILITY CTF II

Dismantled in 2002, after having achieved its goals :

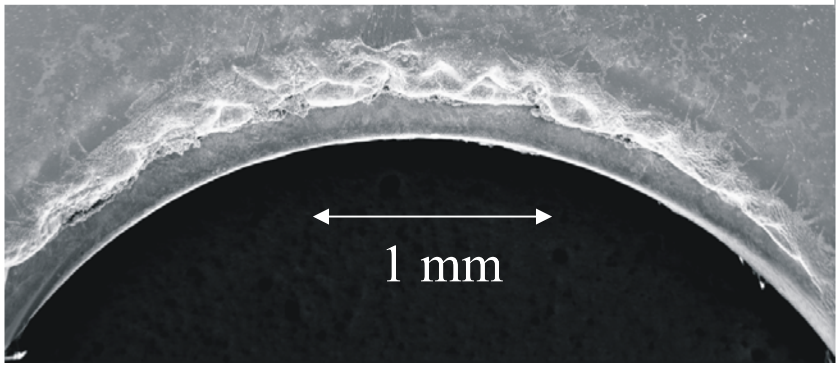
- Demonstrate feasibility of a two-beam acceleration scheme
- Provide high power 30 GHz RF source for high gradient testing (90 MW, 16 ns pulses)
- Study generation of short, intense e-bunches using photocathode RF guns
- Demonstrate operability of μ-precision active-alignment system in accelerator environment
- Provide a test bed to develop and test accelerator diagnostic equipment


CTF II 30 GHz MODULES
Drive beam line
Main beam line

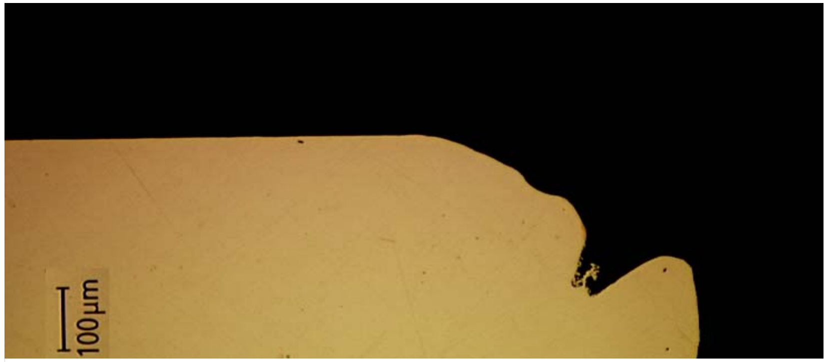
BREAKDOWN AND DAMAGE OF STRUCTURES

High-power tests of copper accelerating structures in **CTF II** and elsewhere indicated that for RF pulses **> 10 ns**, the maximum surface field that can be obtained is around **300-400 MV/m.**

At these field levels structures with large apertures (or rather with large a/@ ratios) seem to suffer **severe surface damage** from breakdowns.



Microscopic image of damaged iris

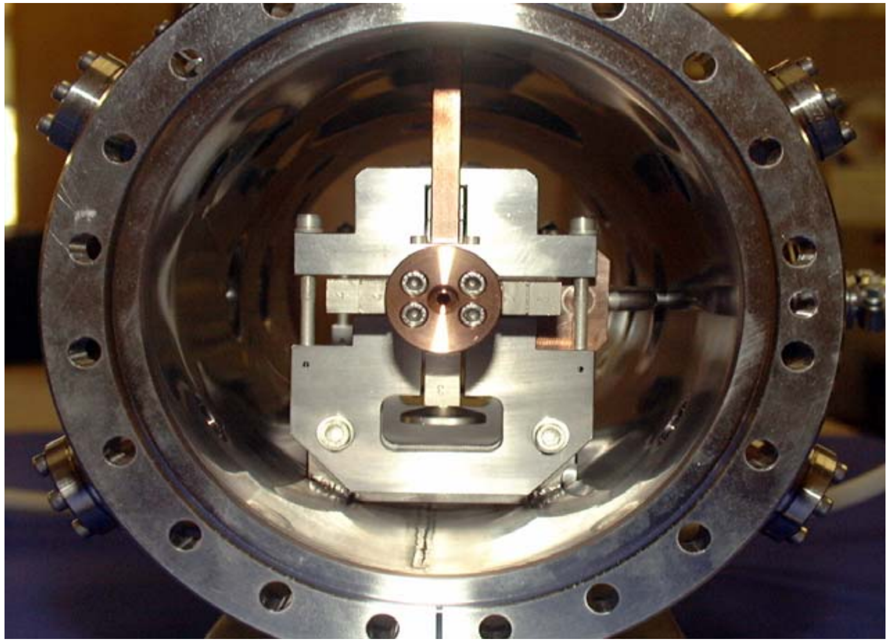


Damaged iris – longitudinal cut

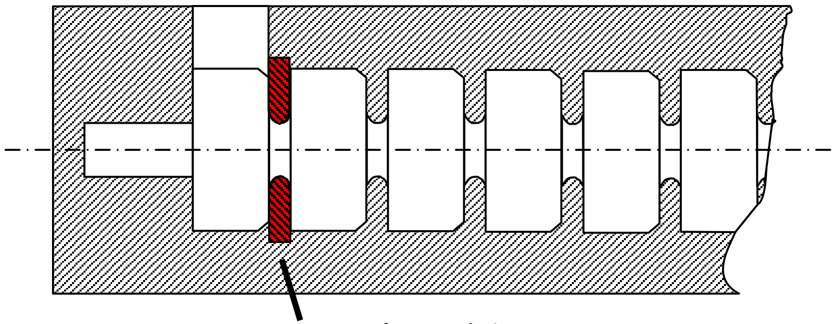
The CLIC study group adopted a two-pronged approach to solving the breakdown problem :

- **Modify the RF design** to obtain smaller a/@ ratios and lower surface field to accelerating field ratio **(Es/Ea ~ 2)**
- Investigating **new materials** that are resistant to arcing - **tungsten** looked promising

FIRST TEST OF TUNGSTEN IRIS IN CTF II

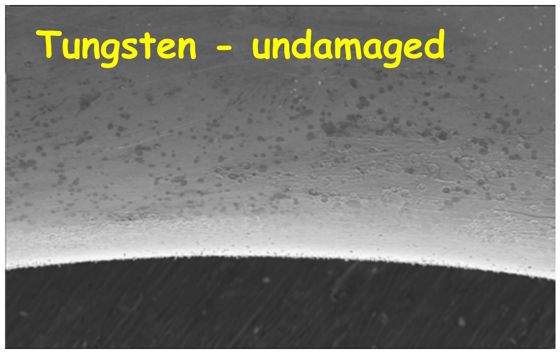


Test structure in external vacuum can, with clamped coupler cell



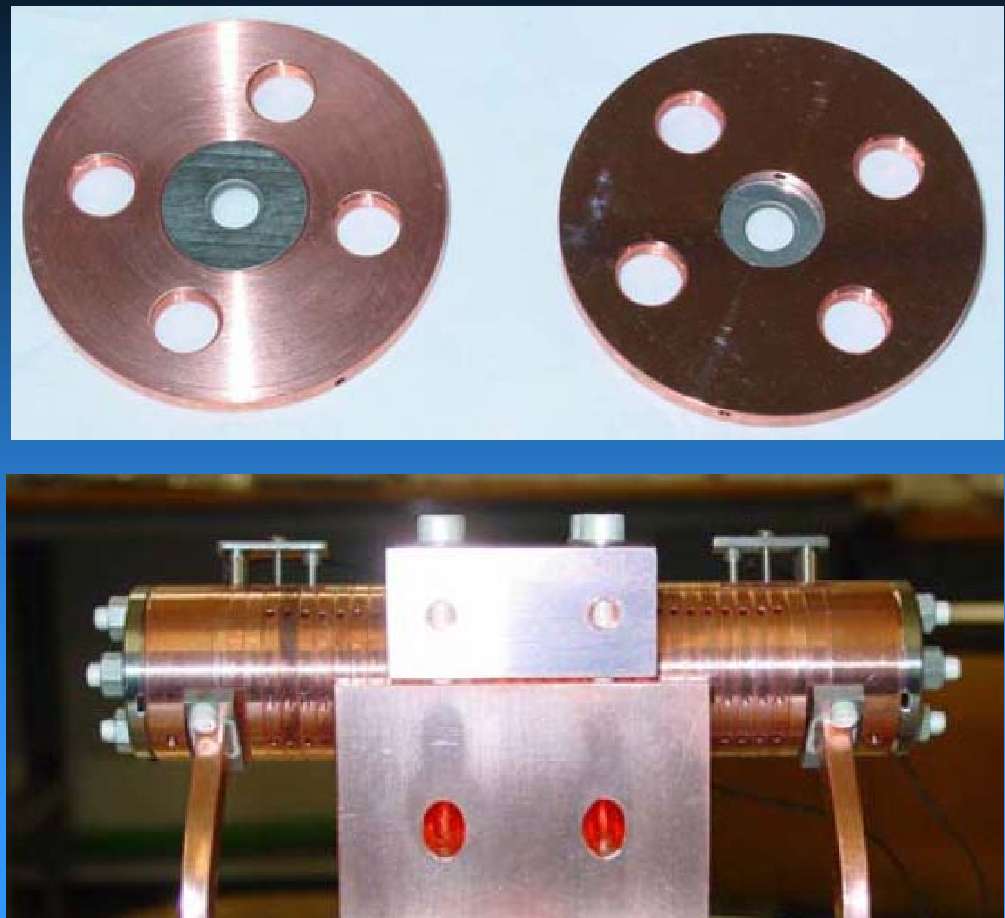
Copper iris replaced by Tungsten iris

Irises after high-gradient testing to about the same field level



HIGH-GRADIENT TESTS in CTF II

30-cell clamped tungsten-iris structure



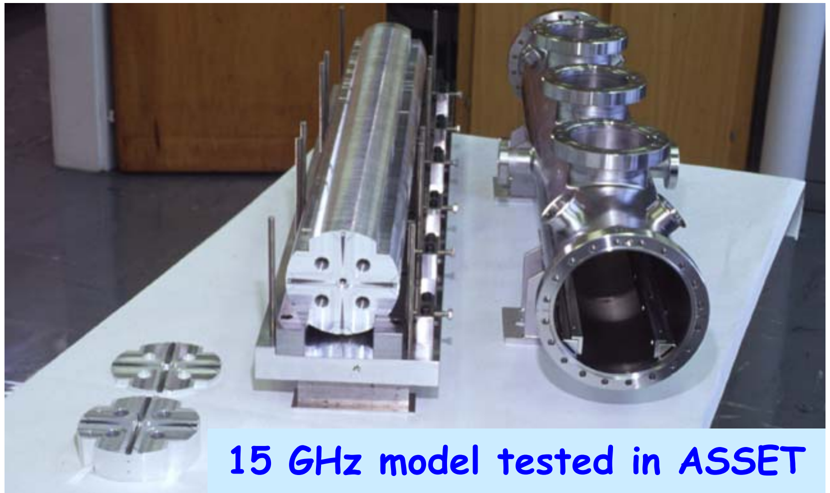
... y exceeded
... amage

190 MV/m accelerating gradient in first cell - tested with beam ! (but only 16 ns pulse length)

CONTROL OF TRANSVERSE WAKEFIELDS

- short-range wakes □ BNS damping
- long-range wakes □ damping and detuning

+ beam-based trajectory correction, *e* bump

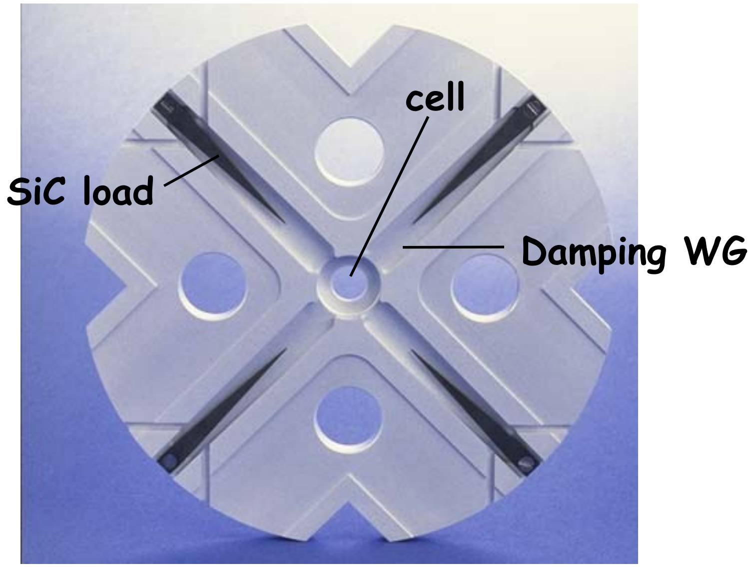


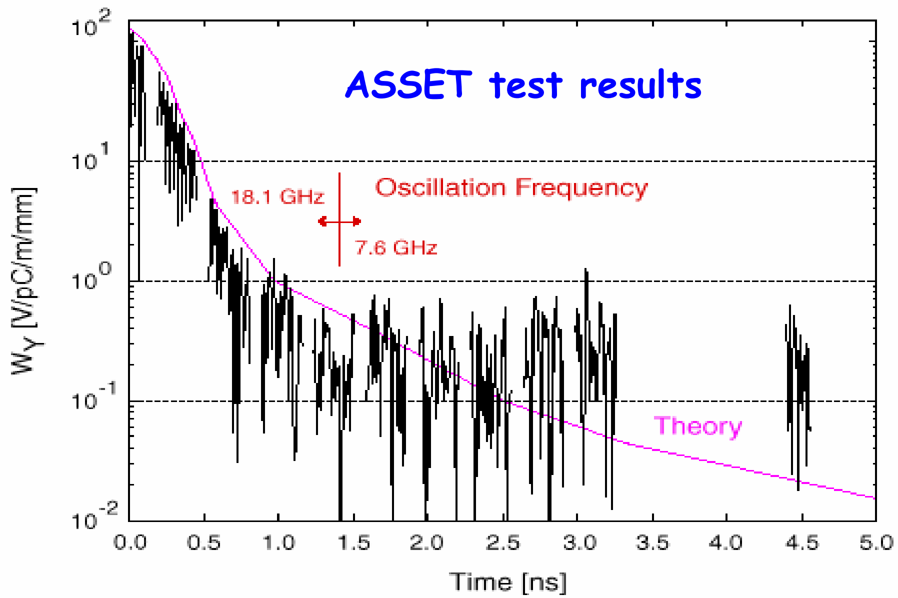
15 GHz model tested in ASSET

For wake suppression - damped structures

Each cell is damped by 4 radial WGs terminated by discrete SiC RF loads.

Excellent agreement obtained between theory and experiment – believe we can solve damping problem





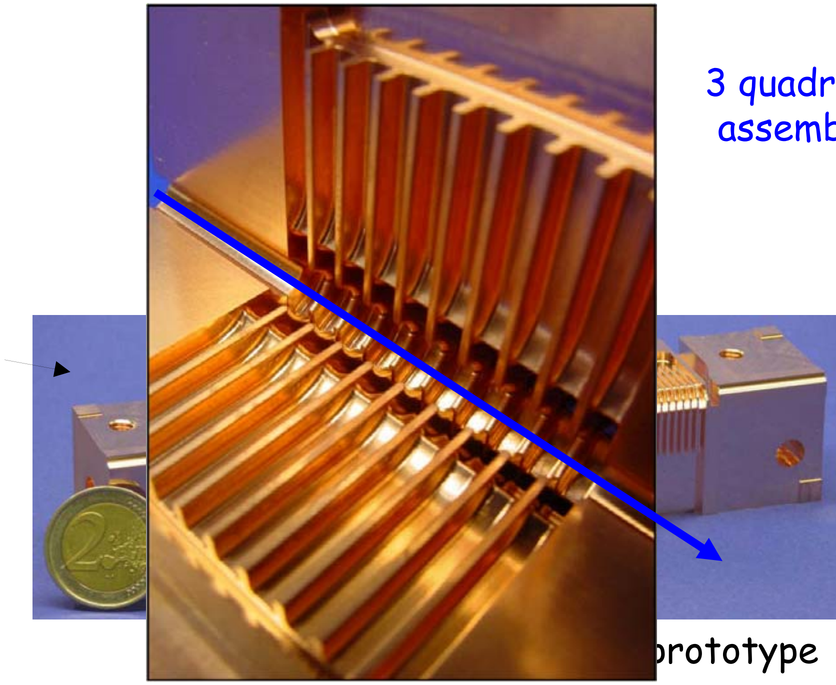
ACCELERATING STRUCTURE DEVELOPMENT

Potential problem: fatigue limit of copper due to cyclic RF pulsed heating →
- Structure design optimization, shorter RF pulse

CTF2 & CTF3 experience →
- New materials, bi-metallic structure assembly, new construction concepts (HDS)

GOAL:

final structure design tested in CTF3 in 2008



3 quadrants assembled

prototype

STABILITY STUDIES

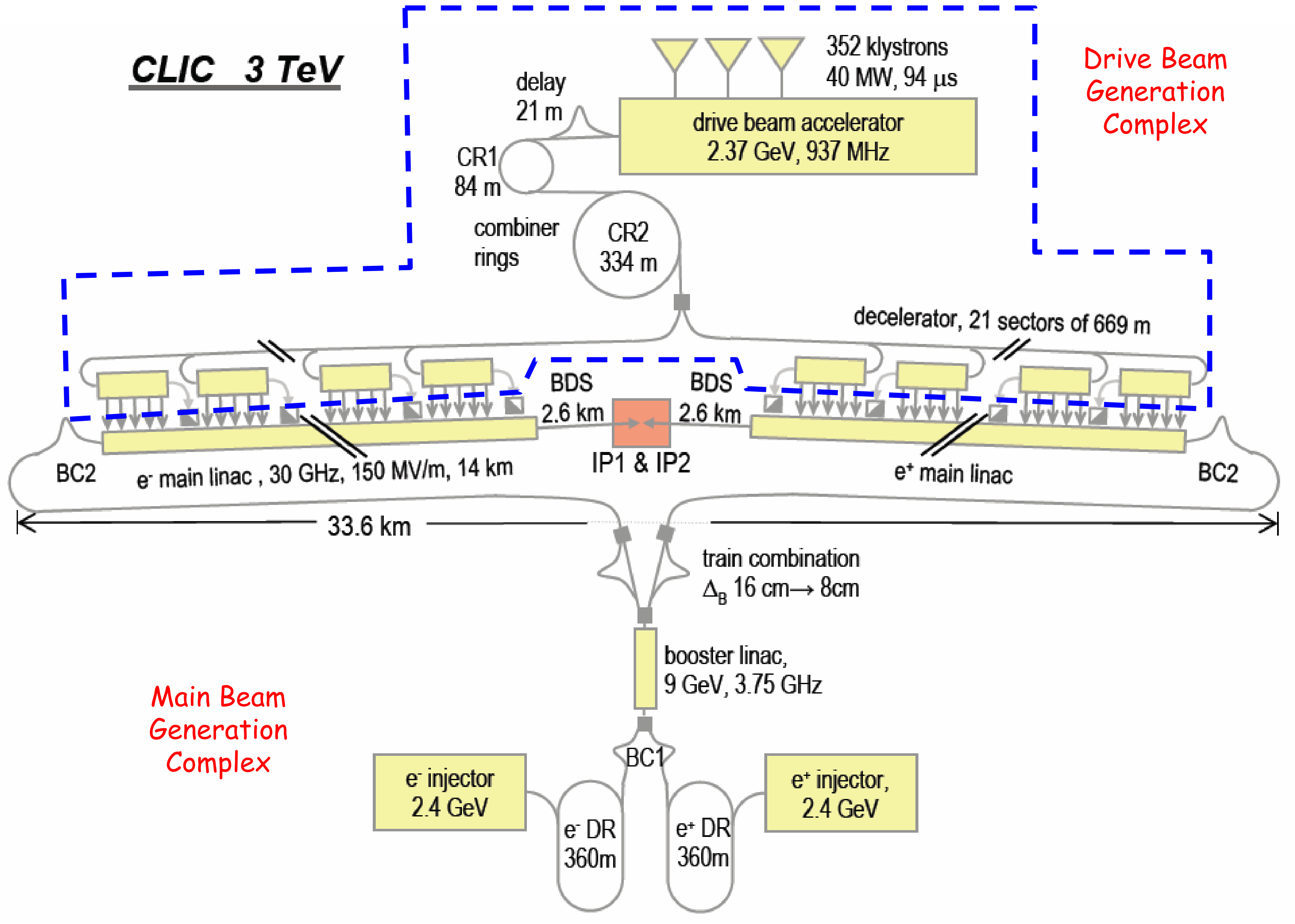
Vertical spot size at IP is ~ 1 nm *(size of water molecule)*

Stability requirements (> 4 Hz) for a 2% loss in luminosity

Magnet	Ix	Iy
Linac (2600 quads)	14 nm	1.3 nm
Final Focus (2 quads)	4 nm	0.2 nm

Need active damping of vibrations

THE CLIC RF POWER SOURCE



WHAT DOES THE RF POWER SOURCE DO ?

The CLIC RF power source can be described as a "black box", combining *very long RF pulses*, and transforming them in *many short pulses*, with *higher power* and with *higher frequency*

350 Klystrons

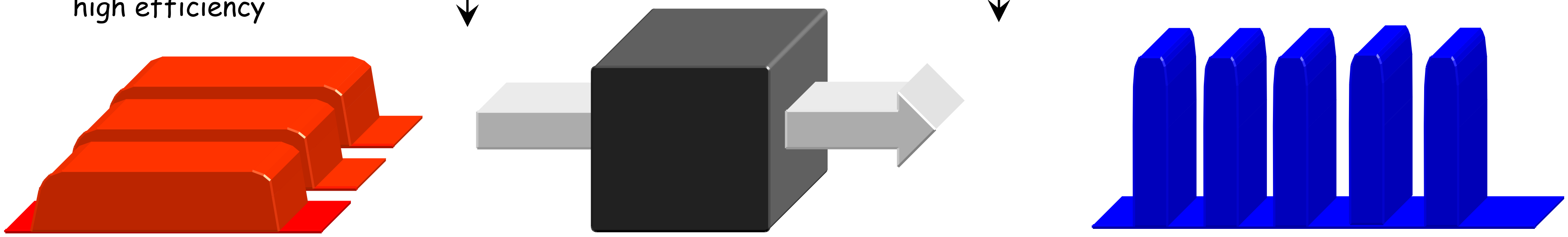
low frequency
high efficiency

Power stored in electron beam

Power extracted from beam in resonant structures

48000 Accelerating Structures

high frequency high gradient



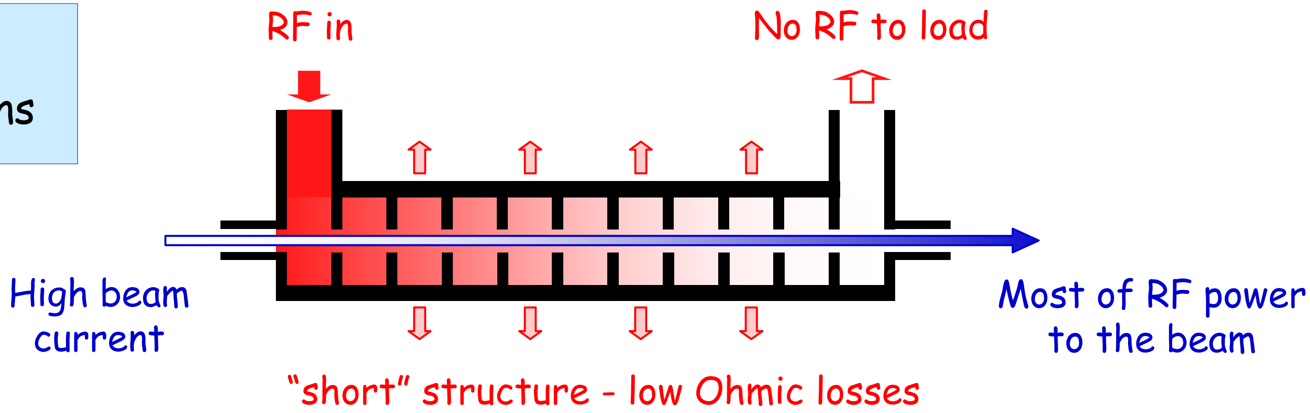
Long RF Pulses
P_0 , n_0 , t_0

Electron beam manipulation

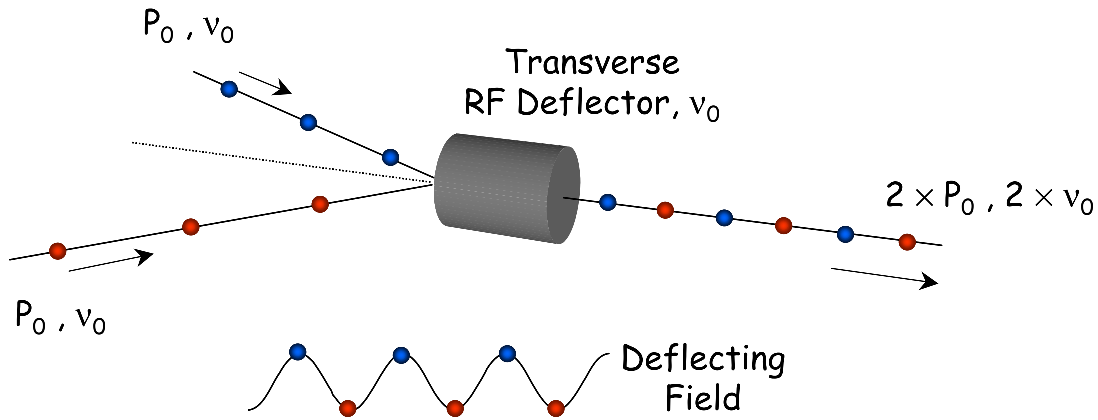
Short RF Pulses
$P_A = P_0$ □ N_1
$t_A = t_0 / N_2$
$n_A = n_0$ □ N_3

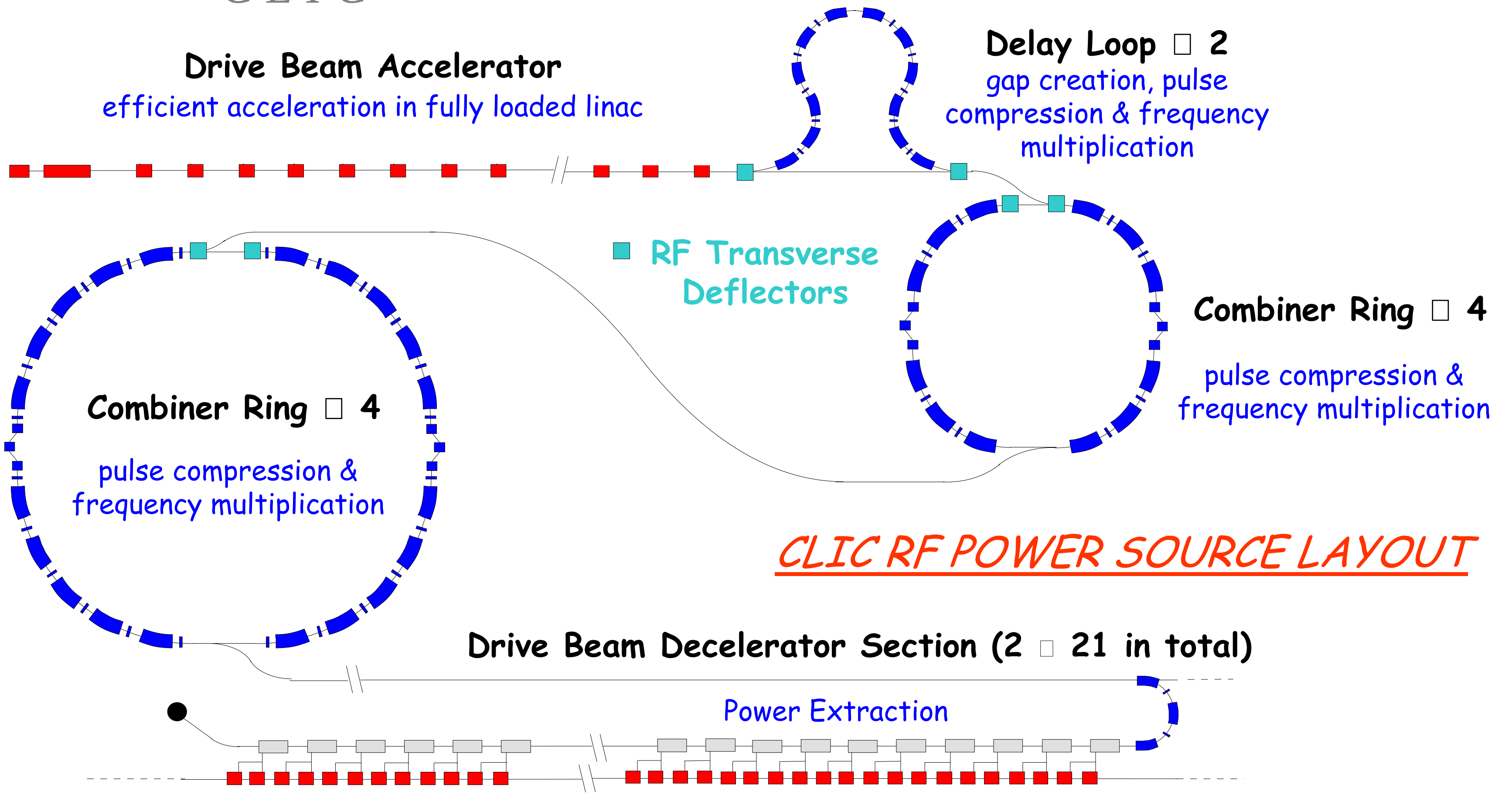
RF POWER SOURCE "BUILDING BLOCKS"

Full beam-loading acceleration in TW sections

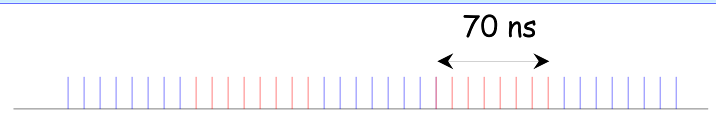


Beam combination/separation by transverse RF deflectors



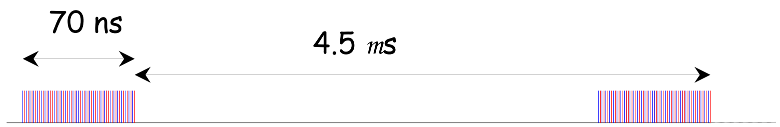


Drive beam time structure - initial



100 ms train length - 32 □ 21 □ 2 sub-pulses - 5.7 A
2.5 GeV - 64 cm between bunches

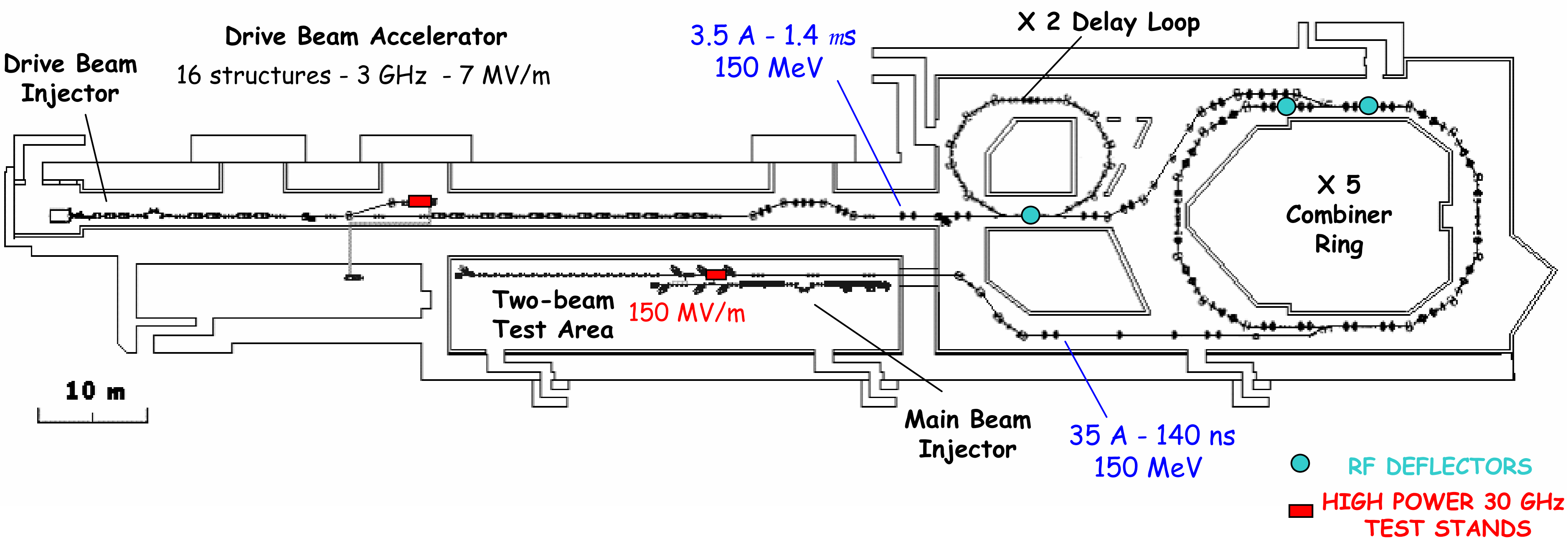
Drive beam time structure - final



2 □ 21 pulses – 180 A - 2 cm between bunches

CTF3 MOTIVATIONS AND GOALS

- Build a small-scale version of the CLIC RF power source, in order to demonstrate:
  - full beam loading accelerator operation
  - electron beam pulse compression and frequency multiplication using RF deflectors
- Provide the 30 GHz RF power to test the CLIC accelerating structures and components at and beyond the nominal gradient and pulse length (150 MV/m for 70 ns) .



CTF3 MOTIVATIONS AND GOALS

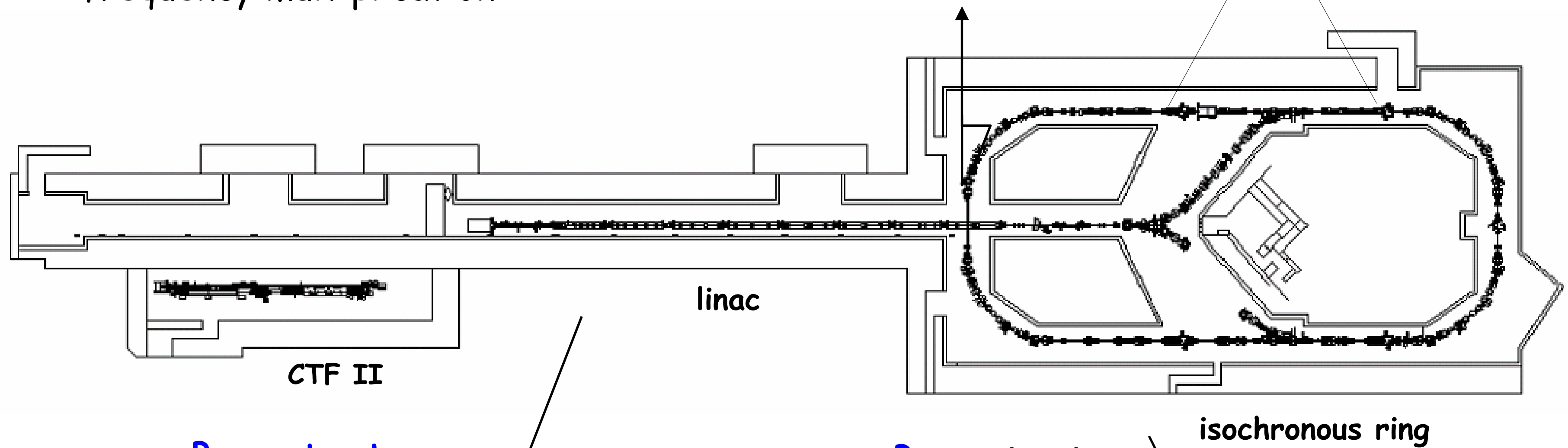
- CTF3 is being built in stages in the area of the former LEP pre-injector complex (LPI). It makes maximum use of the existing equipment (3 GHz RF power plant, magnets…)
- The first phase, CTF3 Preliminary, has given the expected results and has been dismantled.
- An accelerated program is being put in place in order to get all results from CTF3 before 2010:
  - New multilateral collaboration network of volunteer institutes participating jointly to the technical coordination and management of the project.
  - Expression of interest from 14 Institutes at CLIC Collaboration Meeting (28/01/05)

CTF3 COLLABORATION

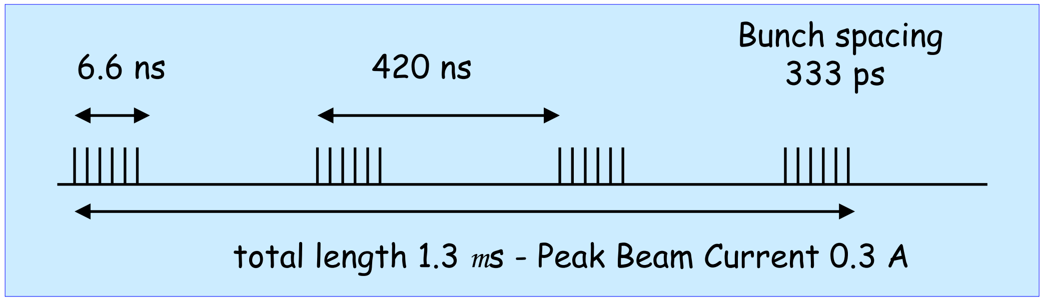
CERN, Geneva (Switzerland)	RAL, (England)	Ankara University , (Turkey)
INFN , Frascati (Italy)	SLAC , San Francisco (USA)	CIEMAT, (Spain)
LAL , Orsay (France)	Uppsala University , (Sweden)	DAPNIA, Saclay (France)
Northwestern University, (USA)		LAPP, Annecy (France)

PRELIMINARY PHASE

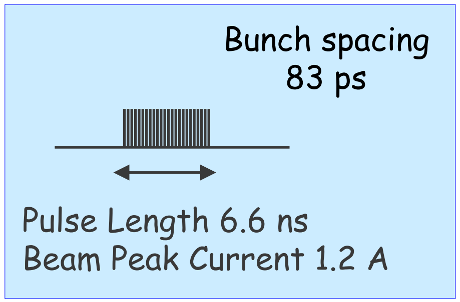
low-charge demonstration of the electron pulse compression and frequency multiplication



Beam structure in linac – 4 pulses



Beam structure after combination (factor 4)



Modifications to the LEP pre-injector complex

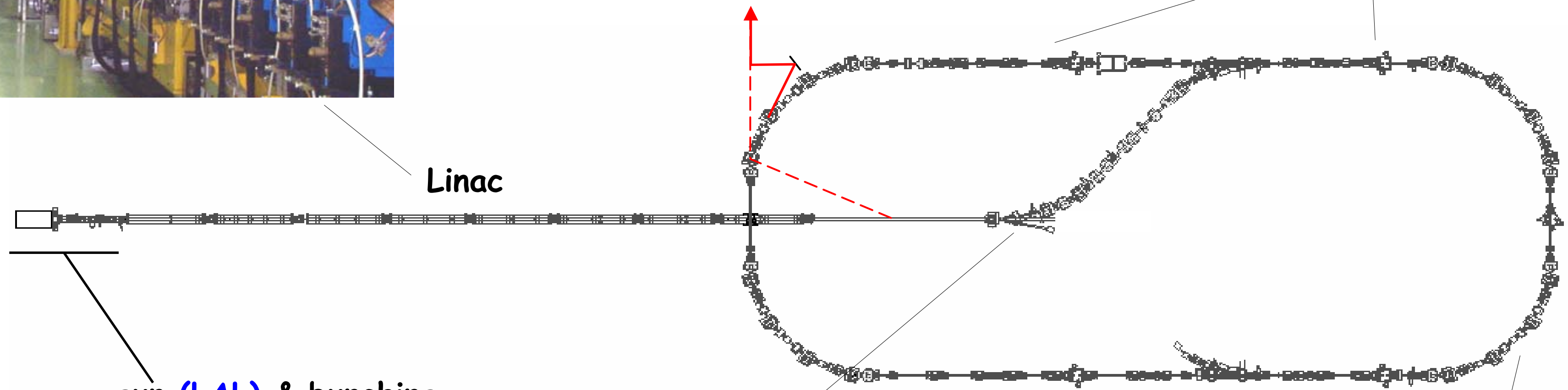
CTF3 PRELIMINARY PHASE

(2001-2002)

streak camera measurement

RF deflectors (INFN-LNF)

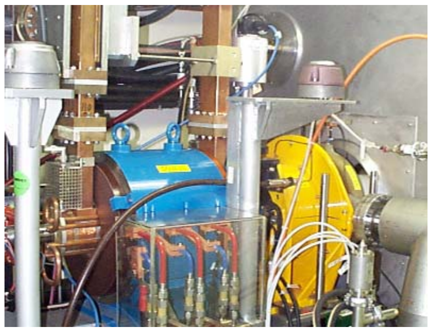
Linac



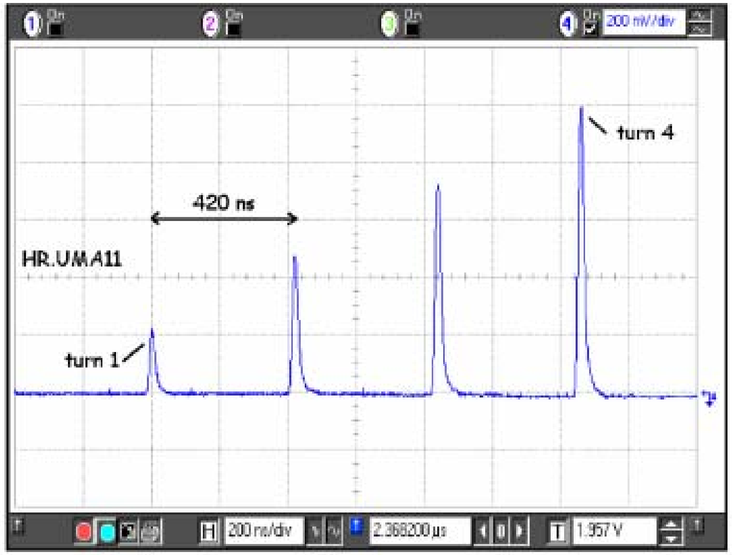
gun (LAL) & bunching system

isochronous arcs

isochronous injection line

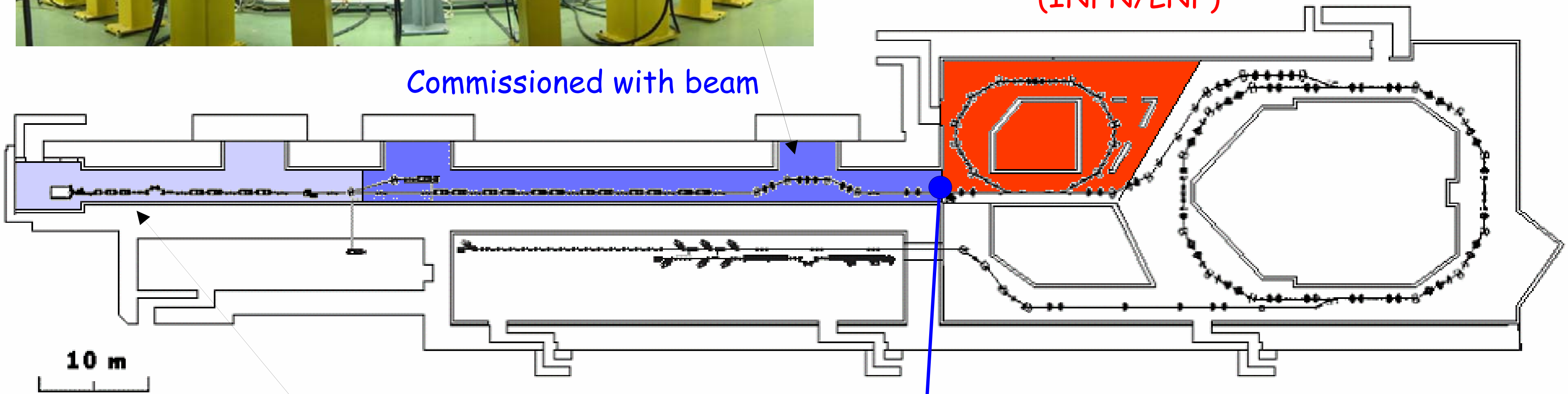


PRELIMINARY PHASE RESULTS
BUNCH COMBINATION (FACTOR 4)



Beam current circulating in the ring measured during combination with a beam current monitor

CTF3 STATUS

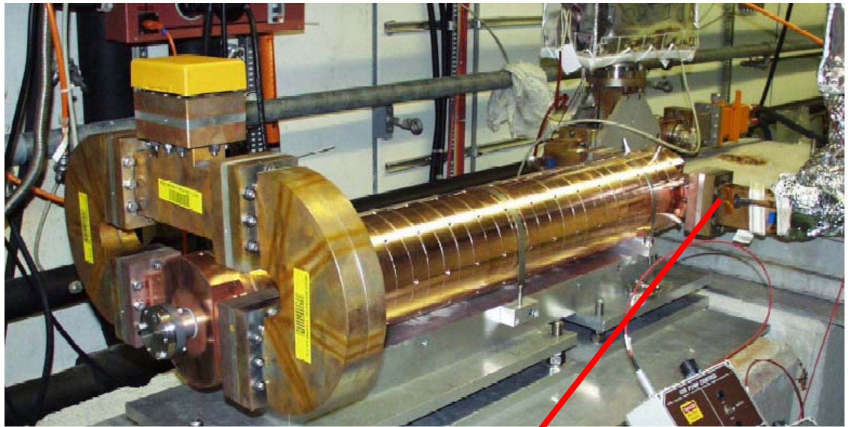


Main beam parameters

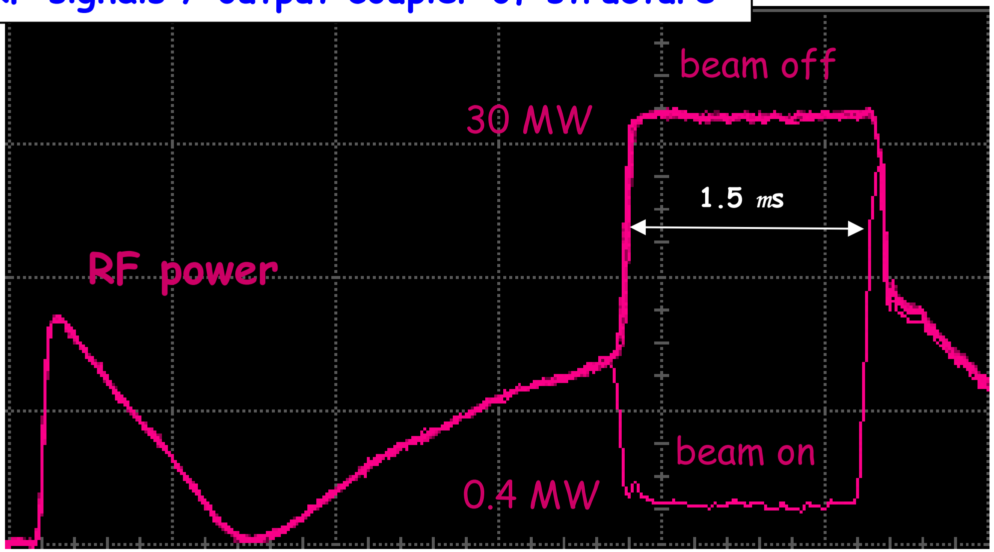
	Nominal	Achieved
I	3.5 A	5 A
t_p	1.5 ms	1.5 ms
E	150 MeV	100 MeV
$e_{n,rms}$	100 p mm mrad	150 p mm mrad *
$t_{b,rms}$	5 ps	4 ps *

* for 3.5 A, 1.5 ms beam

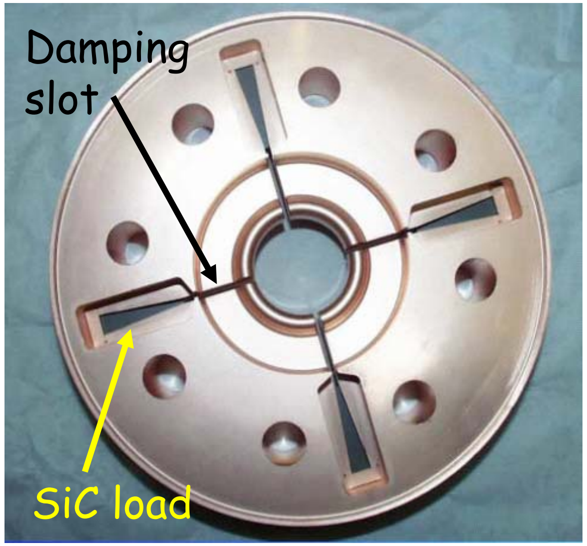
FIRST "FULL" BEAM LOADING OPERATION IN CTF3



RF signals / output coupler of structure

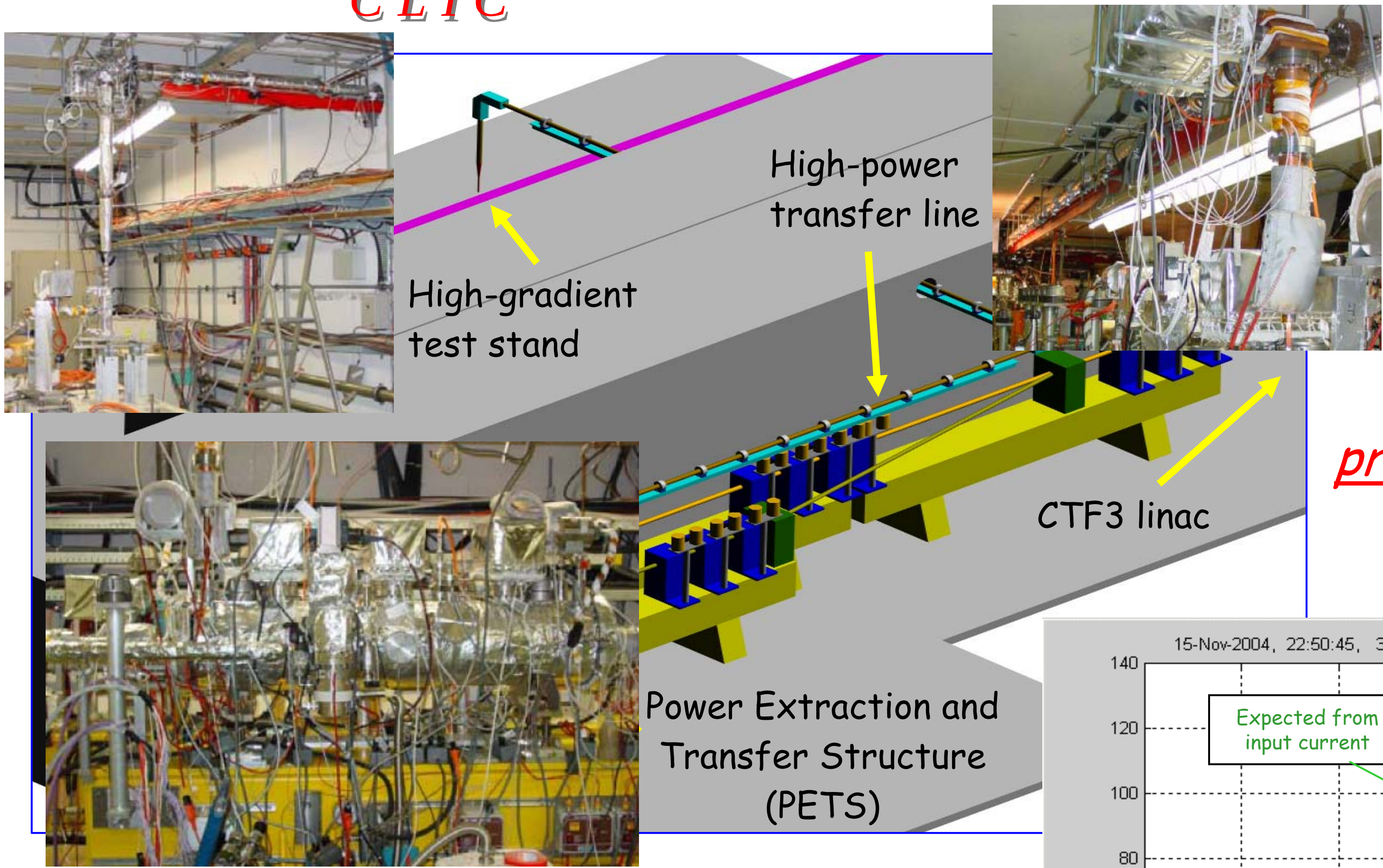


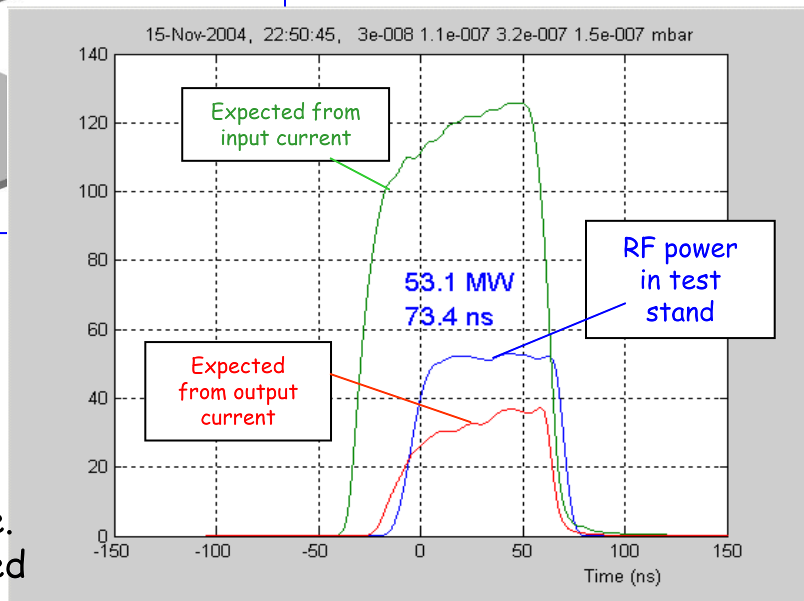
Dipole modes suppressed by slotted iris damping (first dipole's Q factor < 20) and HOM frequency detuning



Beam current	4 A
Beam pulse lenght	1.5 ms
Power input/structure	35 MW
Ohmic losses (beam on)	1.6 MW
RF power to load (beam on)	0.4 MW
RF-to-beam efficiency	~ 94%

30 GHz power production in CTF3

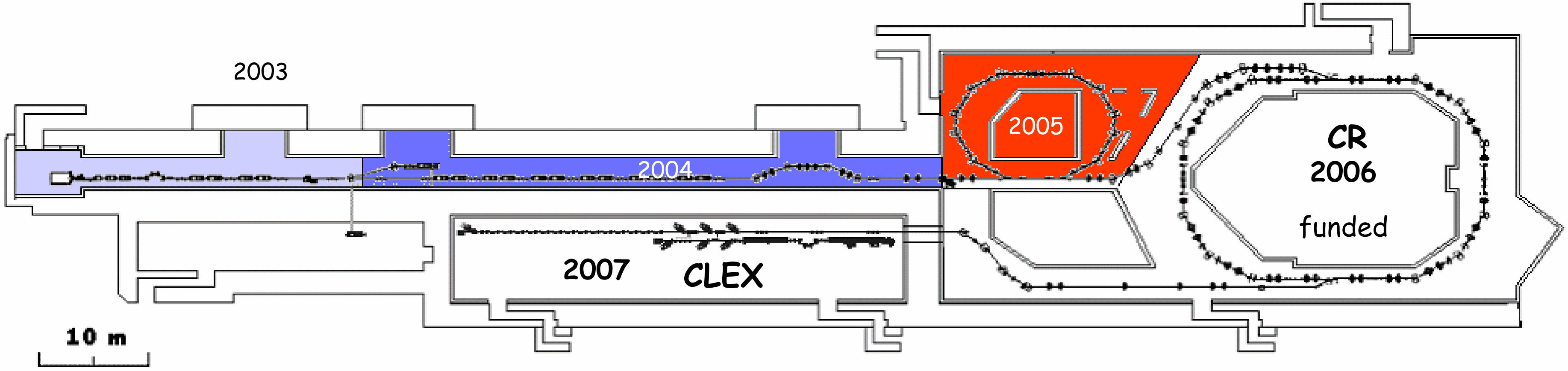




- In 2004, up to 50 MW, 70 ns long pulses produced. Enough to test a CLIC structure to nominal gradient (150 MV/m) and pulse length.
- First structure test in 2005 (Mo iris) limited by run time. About 25 MW (100 MV/m) with 30 ns long pulses reached so far.

Hans Braun for Roberto Corsini
Frontier Science Conf. 14/9/05

CTF3 EVOLUTION



SCHEDULE WITH EXTRA RESOURCES	2004	2005	2006	2007	2008	2009
Drive Beam Accelerator	■					
30 GHz power test stand in Drive Beam accelerator	■	■				
30 GHz power testing (4 months per year)		■	■	■	■	■
R1.1 feasibility test of CLIC structure				■		
Delay Loop	■	■				
Combiner Ring	■	■	■			
R1.2 feasibility test of Drive beam generation				■		
CLIC Experimental Area (CLEX)		■	■			
R1.3 feasibility test PETS				■		
Probe Beam			■	■		
R2.2 feasibility test representativeCLIC linac section					■	
Test beam line		■	■	■	■	
R2.1 Beam stability bench mark tests					■	■

CONCLUSIONS

- CLIC is the only possible scheme to extend the Linear Collider energy into the Multi-TeV range
- CLIC technology is not mature yet, requires challenging R&D
- Very promising results were already obtained in CTF II and in the first stages of CTF3
- Remaining key issues clearly identified (ILC-TRC)
- Technology independent key issues studied within EuroTeV and in close collaboration with ILC
- All CLIC specific feasibility issues addressed in CTF3 before 2010

Aim to demonstrate the feasibility of CLIC technology in due time, when HEP community needs will be understood from LHC results