CLIC challenges - Talk outline

- Introduction - CLIC peculiarities
- The ILC-TRC 2003 recommendations
- R&D results so far for baseline program
  - Accelerating structures
  - Drive beam generation & power production
  - Others
- Other issues
  - Generation of low emittance
  - Alignment and stability
  - Diagnostics
  - Phase stability
- Conclusions

What matters in a linear collider ?

Energy reach

$$E_{cm} = 2 F_{fill} L_{linac} G_{RF}$$

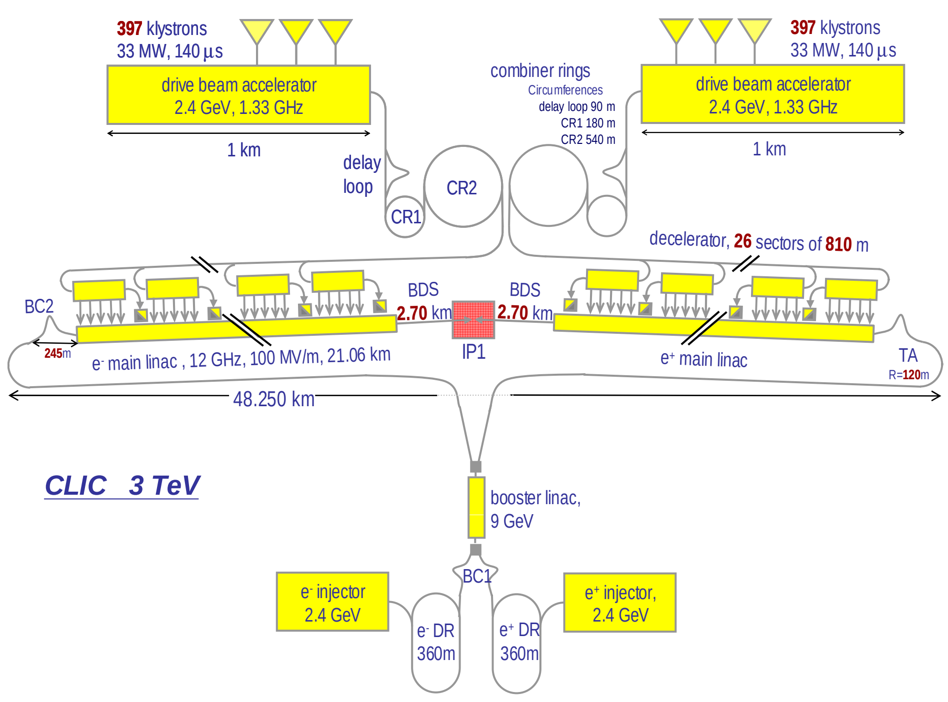
- High gradient

Luminosity

$$L = \frac{n_b N^2 f_{rep}}{4\pi\sigma_x^* \sigma_y^*} \times H_D \propto \frac{\eta_{beam}^{AC} P_{AC}}{\varepsilon_y^{1/2}} \frac{\delta_{BS}^{1/2}}{E_{cm}}$$

- Acceleration efficiency
- Generation of small emittance — damping rings
- Conservation of small emittance — wake-fields, alignment, stability
- Extremely small beam spot at Interaction Point — beam delivery system, stability

The CLIC way to a multi-TeV linear collider - Basic features



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

- High acceleration gradient (100 MV/m)
  - "Compact" collider - overall length < 50 km
  - Normal conducting accelerating structures
  - "High" acceleration frequency (12 GHz)
- Two-Beam Acceleration Scheme
  - Cost effective, potentially reliable
  - Efficient (~ 8% overall)
  - Simple tunnel, no active elements
  - Easy upgrade to higher energies
- Small emittance & small beam spot @ I.P.
  - High Luminosity to beam power ratio

The *CLIC Technology-related* key issues as pointed out by ILC-TRC 2003

Covered by CTF3

R1: Feasibility

- R1.1: Test of damped accelerating structure at design gradient and pulse length
- R1.2: Validation of drive beam generation scheme with fully loaded linac operation
- 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

Other R2 key issues- *common to all projects* - as pointed out by ILC-TRC 2003

Damping Rings

- electron cloud effects
- fast ion instability
- extraction kicker stability
- emittance correction

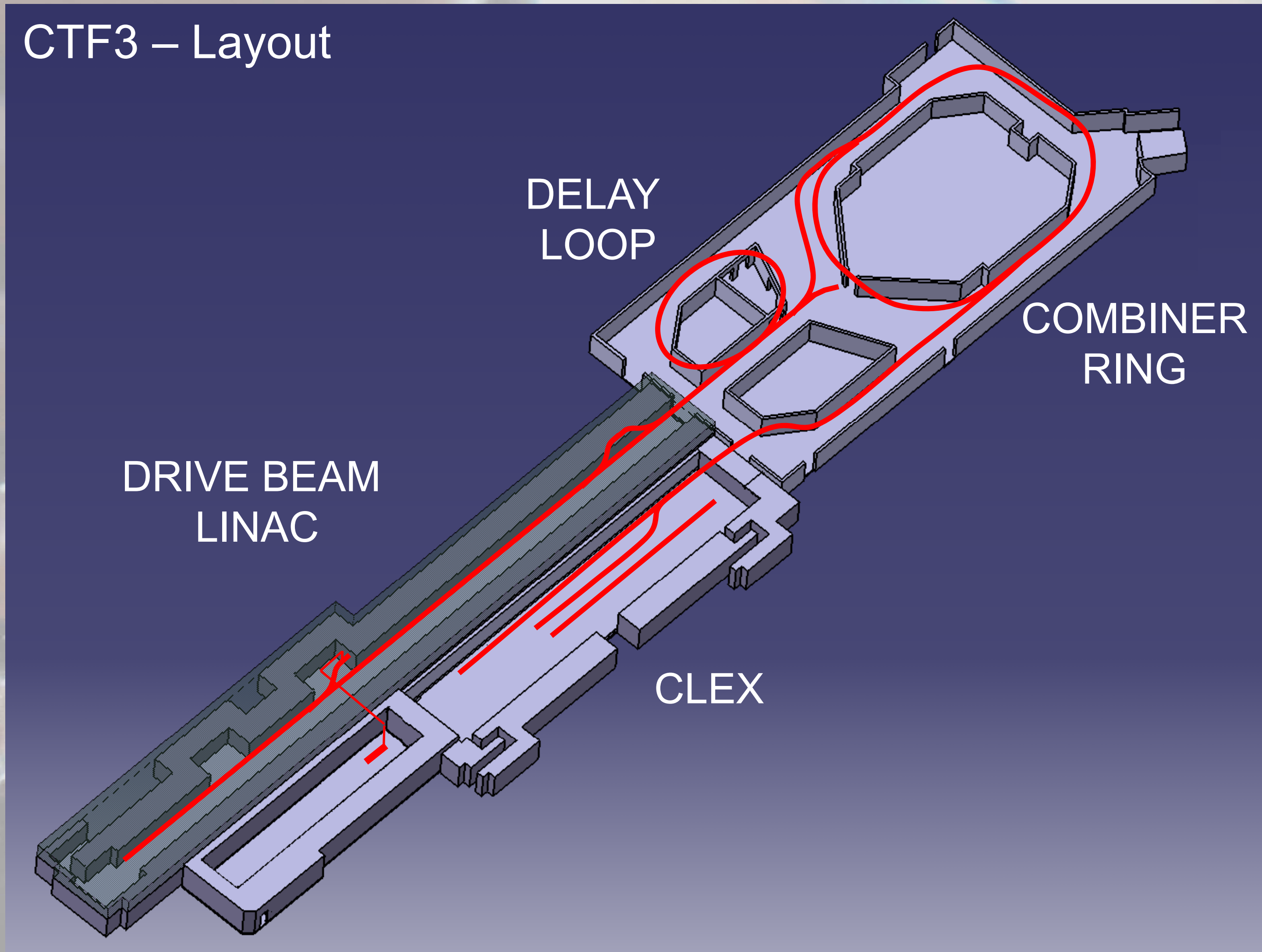
Low emittance transport

- static tuning studies, dynamic effects during correction
- beam instrumentation (luminosity monitor, laser-wire profile monitor)
- prototype of the main linac module (on-girder sources of vibration)

Reliability

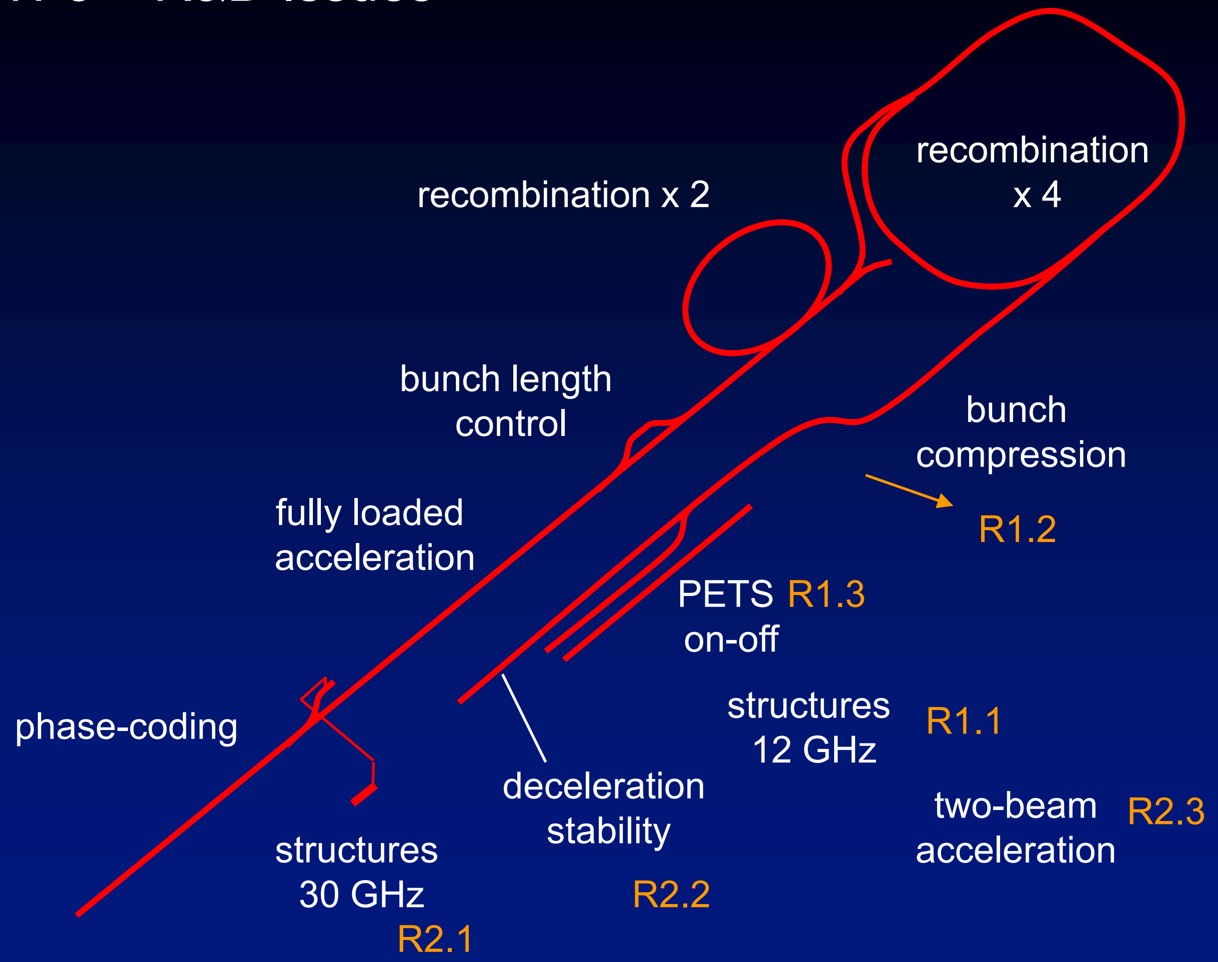
- detailed evaluation of critical subsystem reliability
- performance of beam based tuning procedures by complete simulations

Still relevant & complete ?

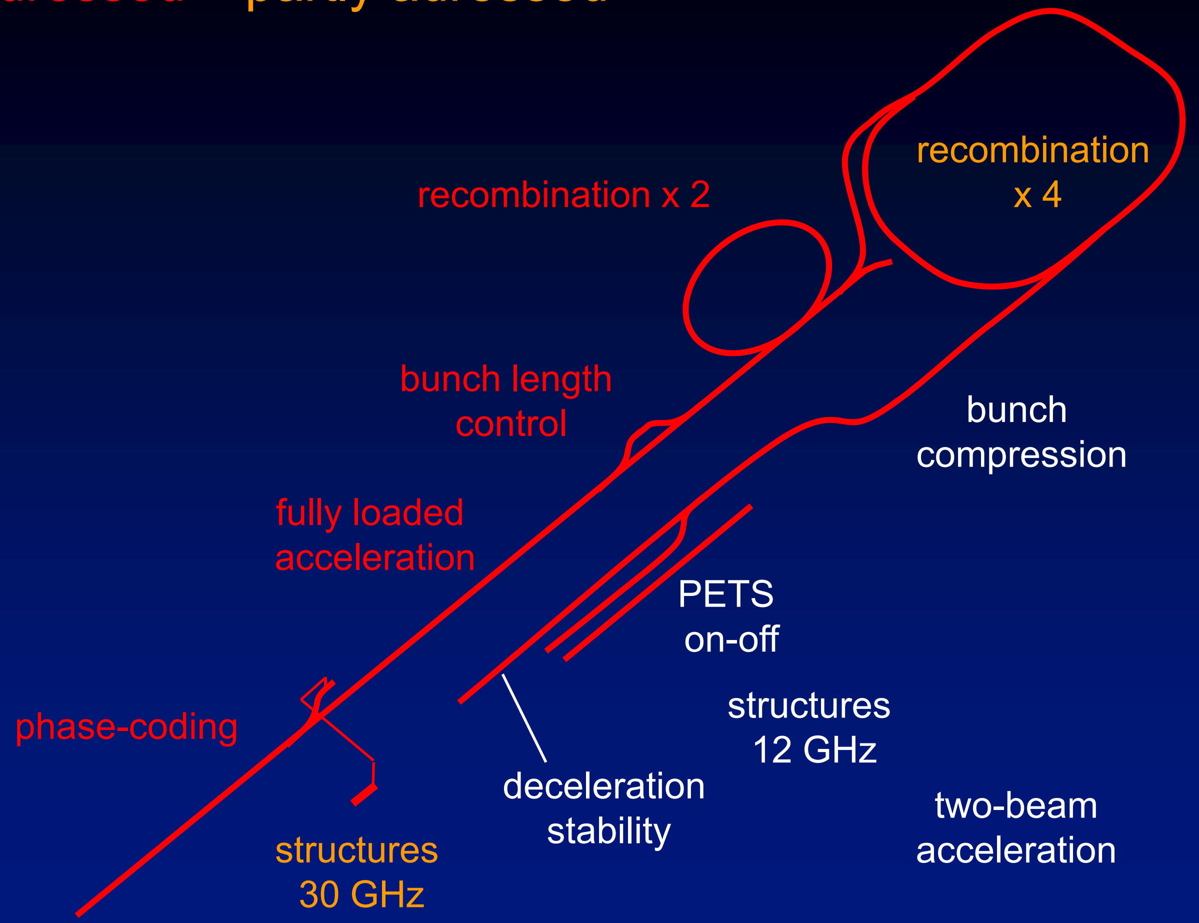

CTF3 – Layout
DELAY LOOP
COMBINER RING
DRIVE BEAM LINAC
CLEX

CTF3 – Main components

CTF3 – R&D Issues



Adressed – partly adressed



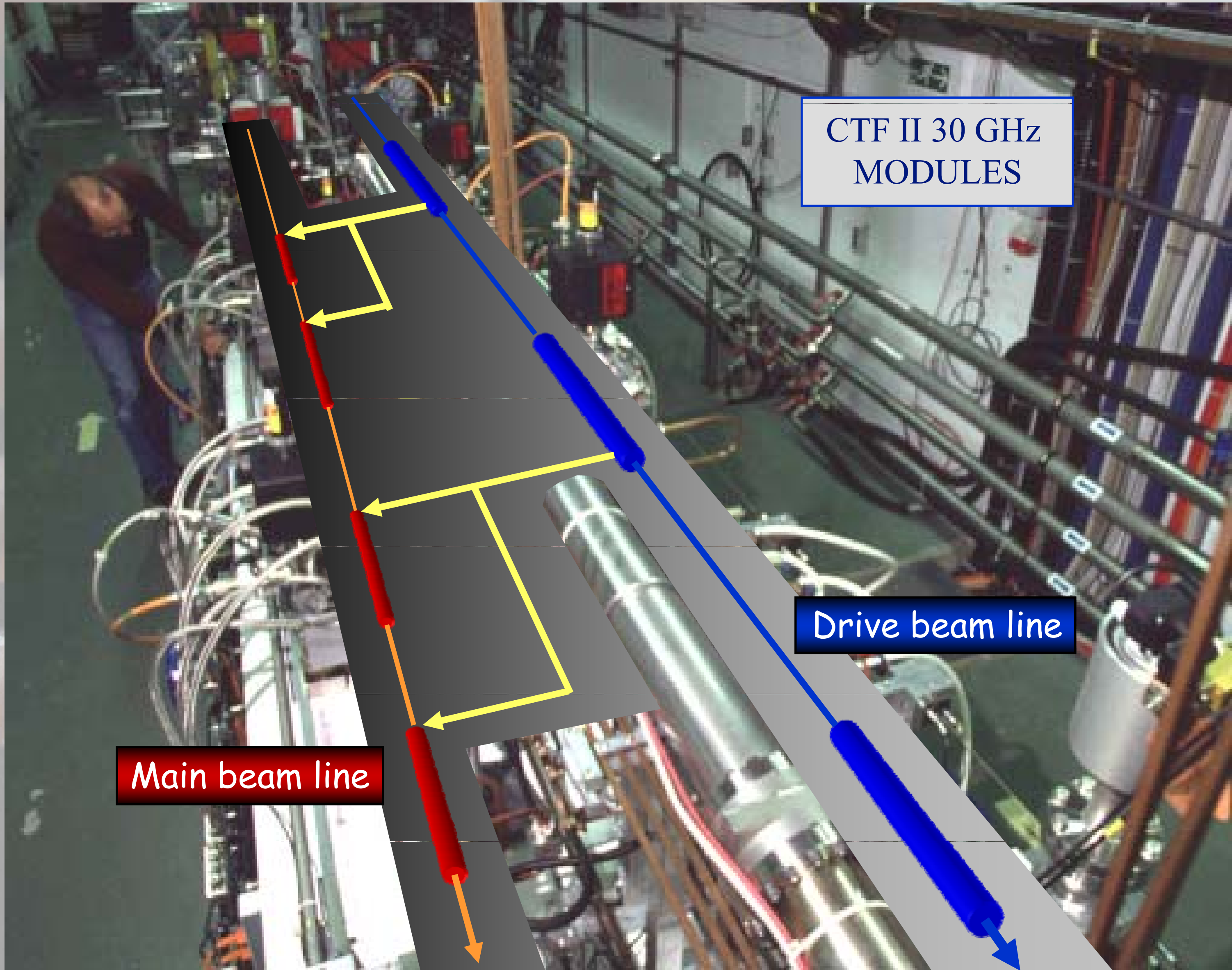
R1.1: Test of damped accelerating structure at design gradient and pulse length

The presently tested CLIC structures have only been exposed to very short pulses (30 ns maximum) and were not equipped with wakefield damping. The first Ranking 1 R&D issue is to test the complete CLIC structures at the design gradient and with the design pulse length (130 ns). Tests with design pulse length and with undamped structures are foreseen when CTF3 is available (April 2004).

R2.1: Developments of structures with hard-breaking materials (W, Mo…)

Present tests have demonstrated the advantages of tungsten and molybdenum irises in reaching the highest gradients in accelerator structures. These tests should be pursued, possibly also with other materials, for application to CLIC and possibly other machines.

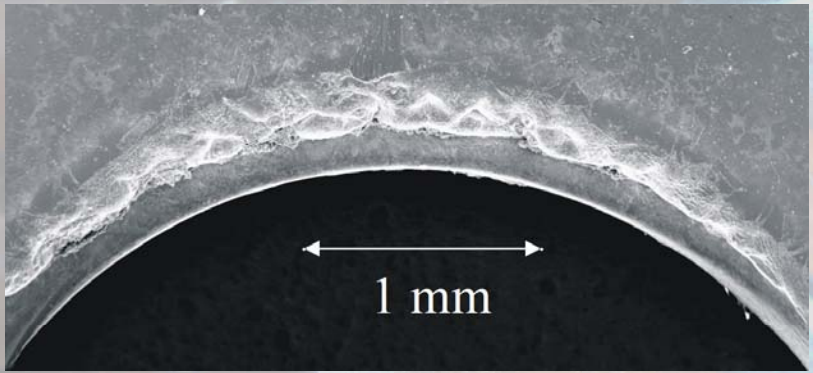
CTF II - Dismantled in 2002, after having achieved its goals



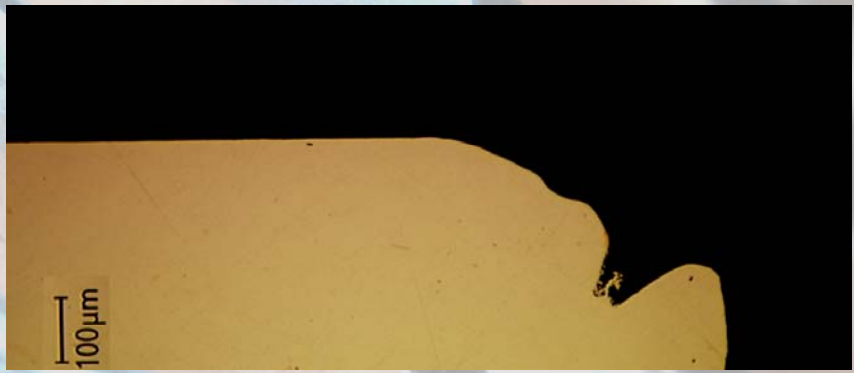
Breakdown and damage of structures

High-power tests of copper accelerating structures in **CTF II** and elsewhere showed a maximum surface field around **300-400 MV/m.**

At these field levels structures seem to suffer **severe surface damage** from breakdowns.



Microscopic image of damaged iris

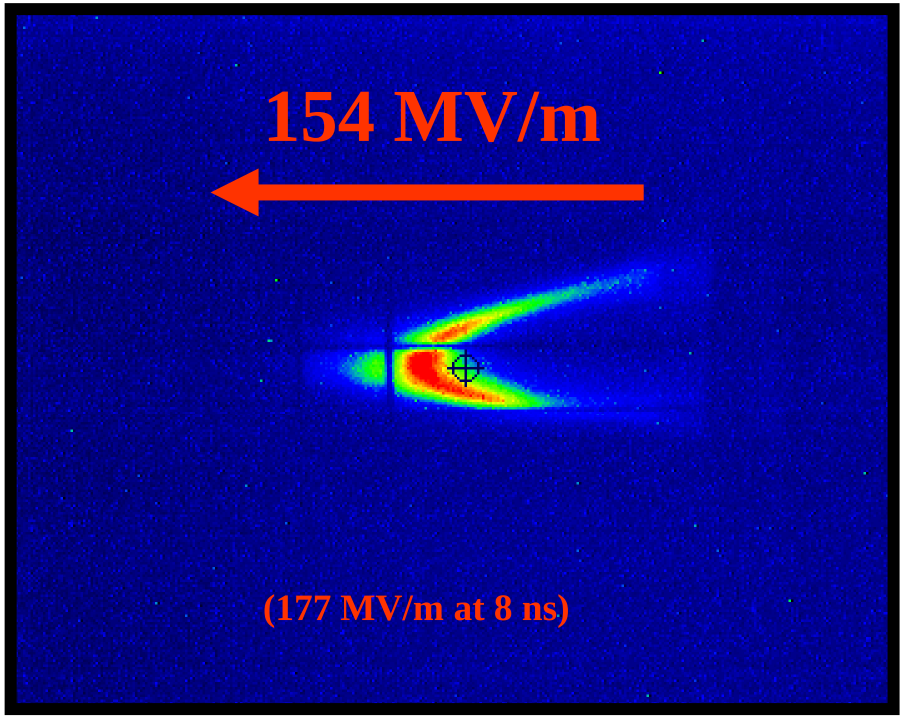


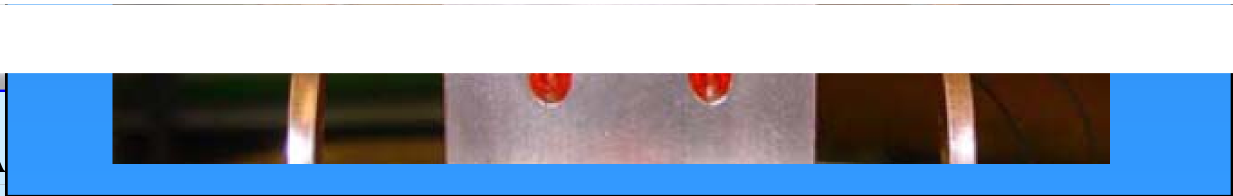
Damaged iris – longitudinal cut

Possible solutions:

- Optimize the **RF design** to obtain lower surface field to accelerating field ratio **(small a/λ)**
- Investigating **new materials** that are resistant to arcing - **tungsten** looked promising

High-gradient tests in CTF II

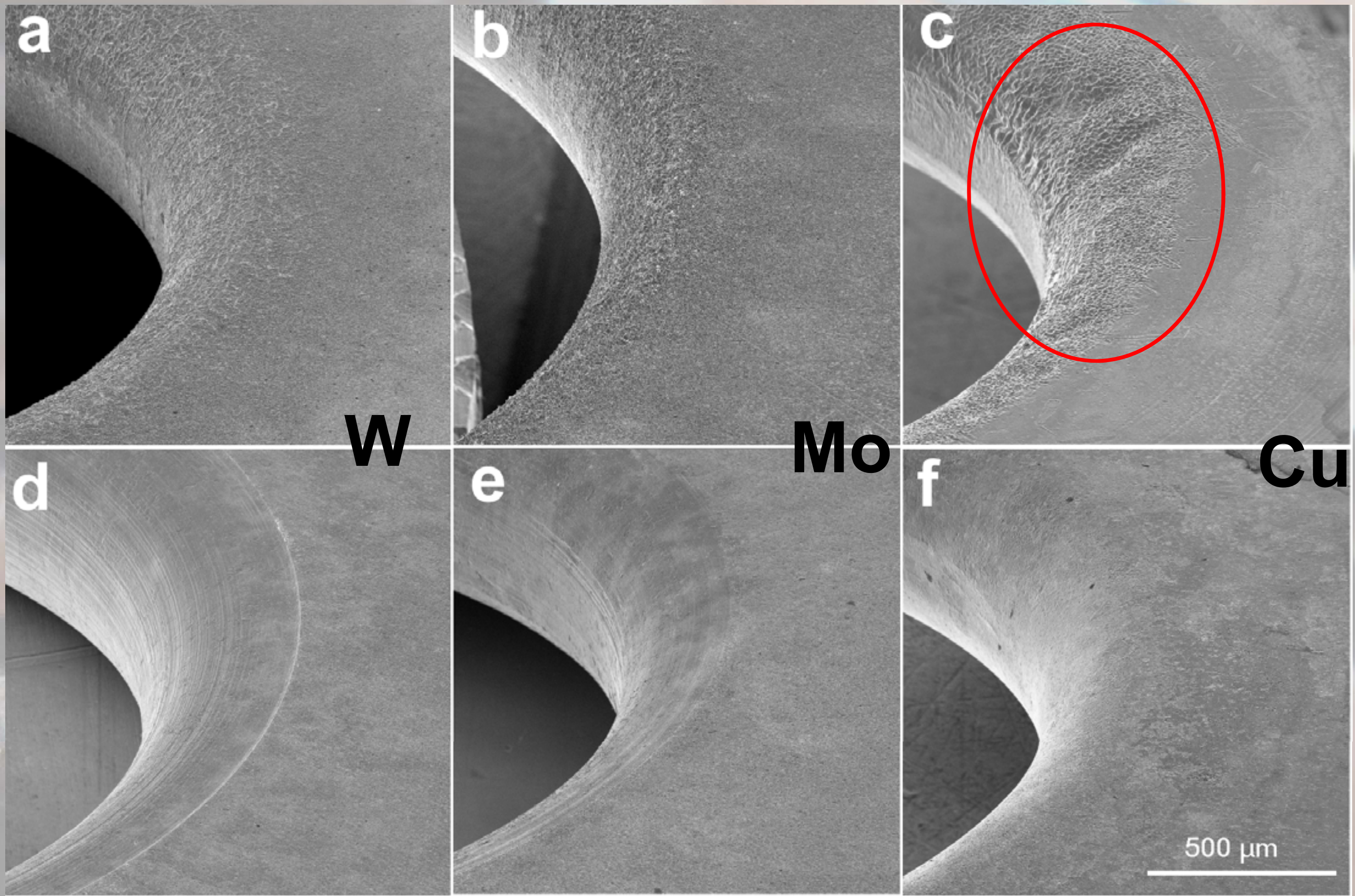




A … LIC
accelerating field requirements without any damage

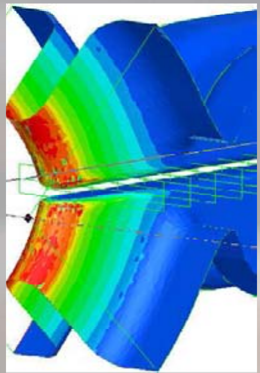
190 MV/m accelerating gradient in first cell - tested with beam ! (but only 16 ns pulse length)

High-gradient tests in CTF II



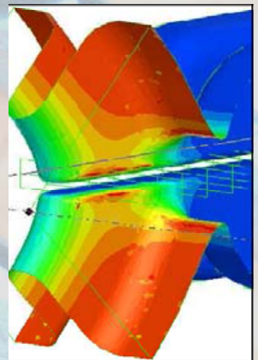
Damage on iris after runs of the 30-cell clamped structures tested in CTFII.
First (a, b and c) and generic irises (d, e and f) of W ,Mo and Cu structures respectively.

Structure limitations - bi-metallic concept



E-field (breakdown)

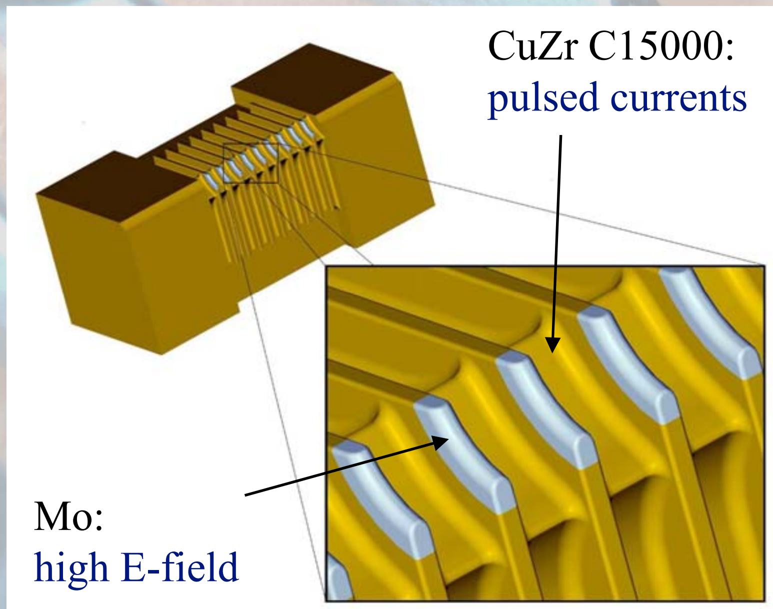
⇨use of **Mo**, or alternative refractory metal.



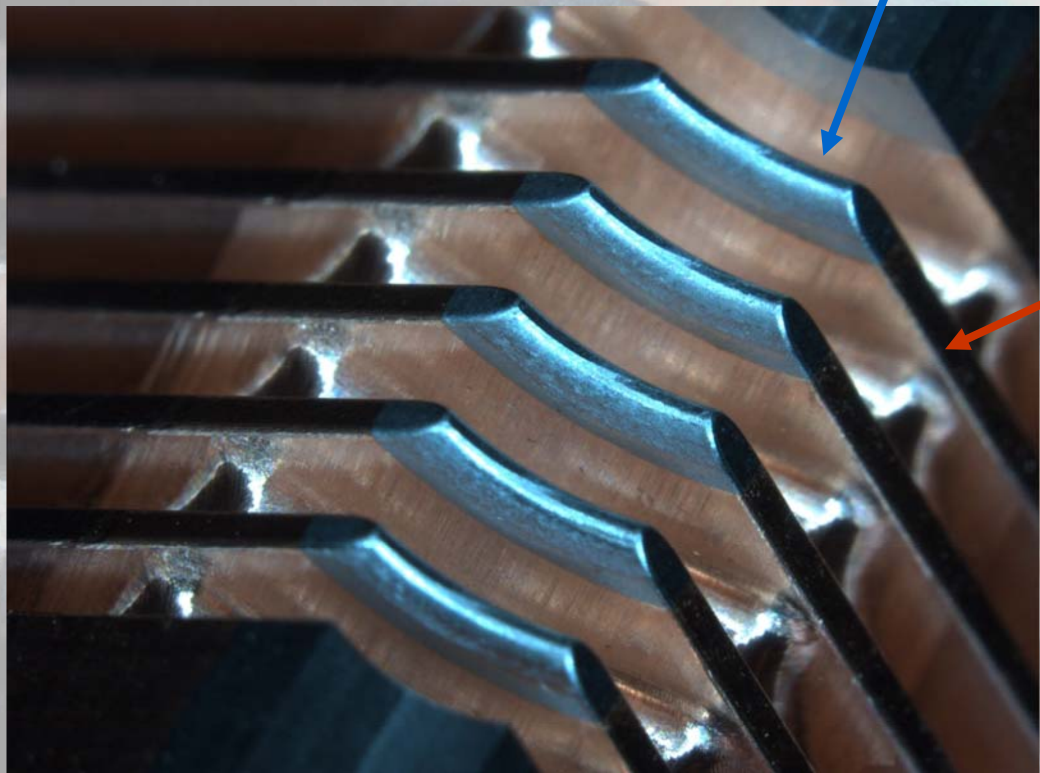
Pulsed currents (fatigue)

⇨ use of **CuZr**, or improved mechanical strength high conductivity alloy.

⇨Use bi-metallic



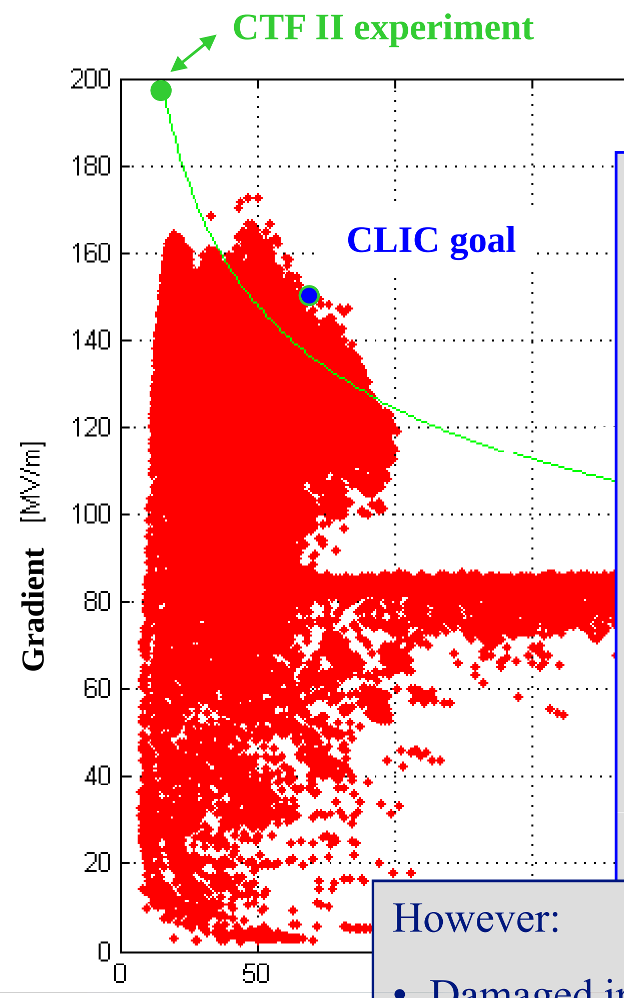
Acceleration structure fabrication tests



Bi-metallic structure
Hot Isostatic Pressing

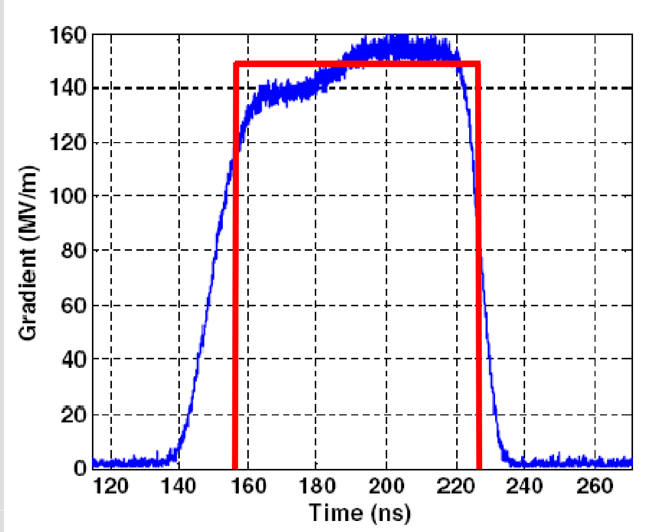
CTF3 High-Power test results

Accelerating structure test in CTF3
(Mo iris - clamped)



Reached nominal CLIC values :

150 MV/m - 70 ns



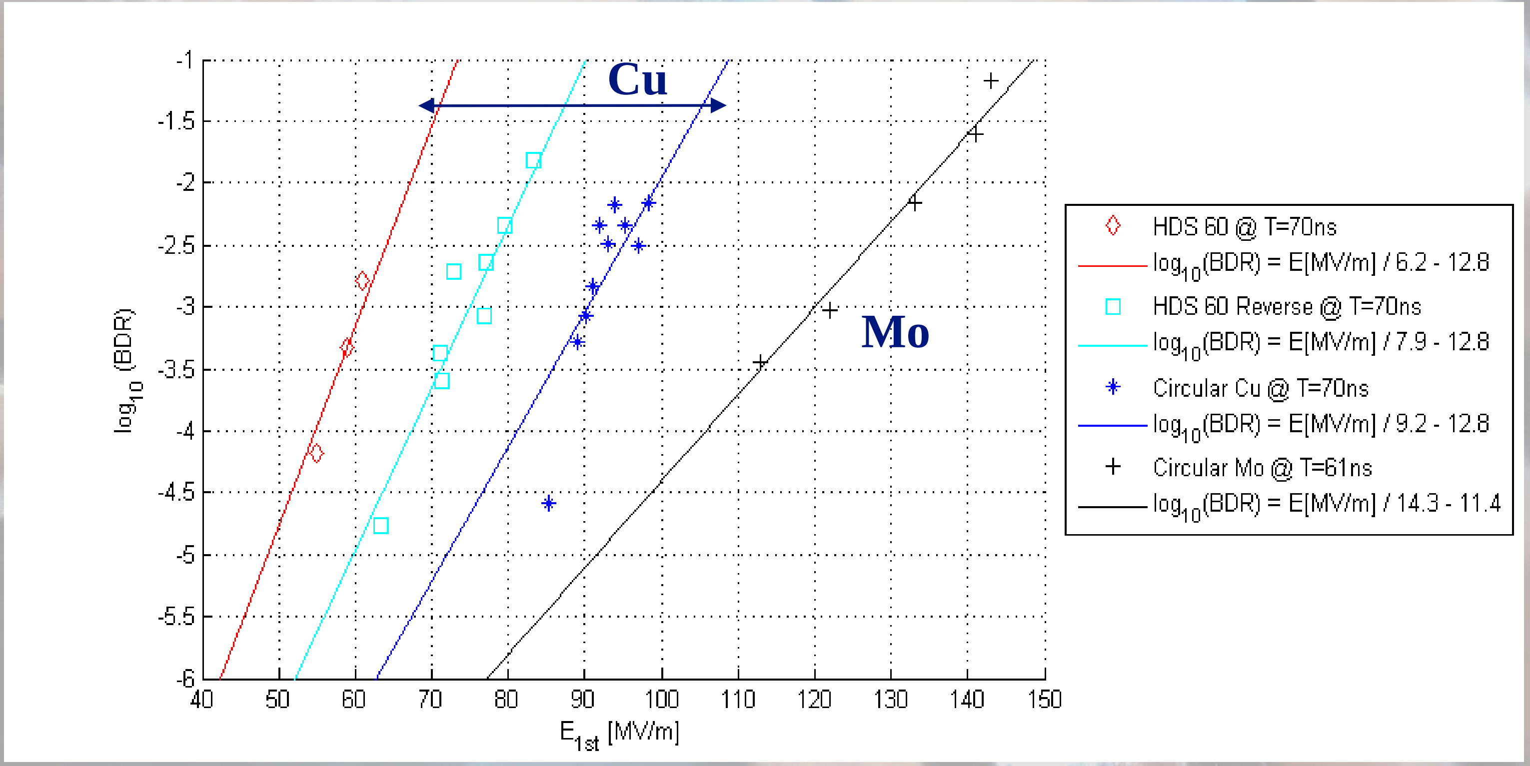
However:

- Damaged irises
- Breakdown rate too high for CLIC operation

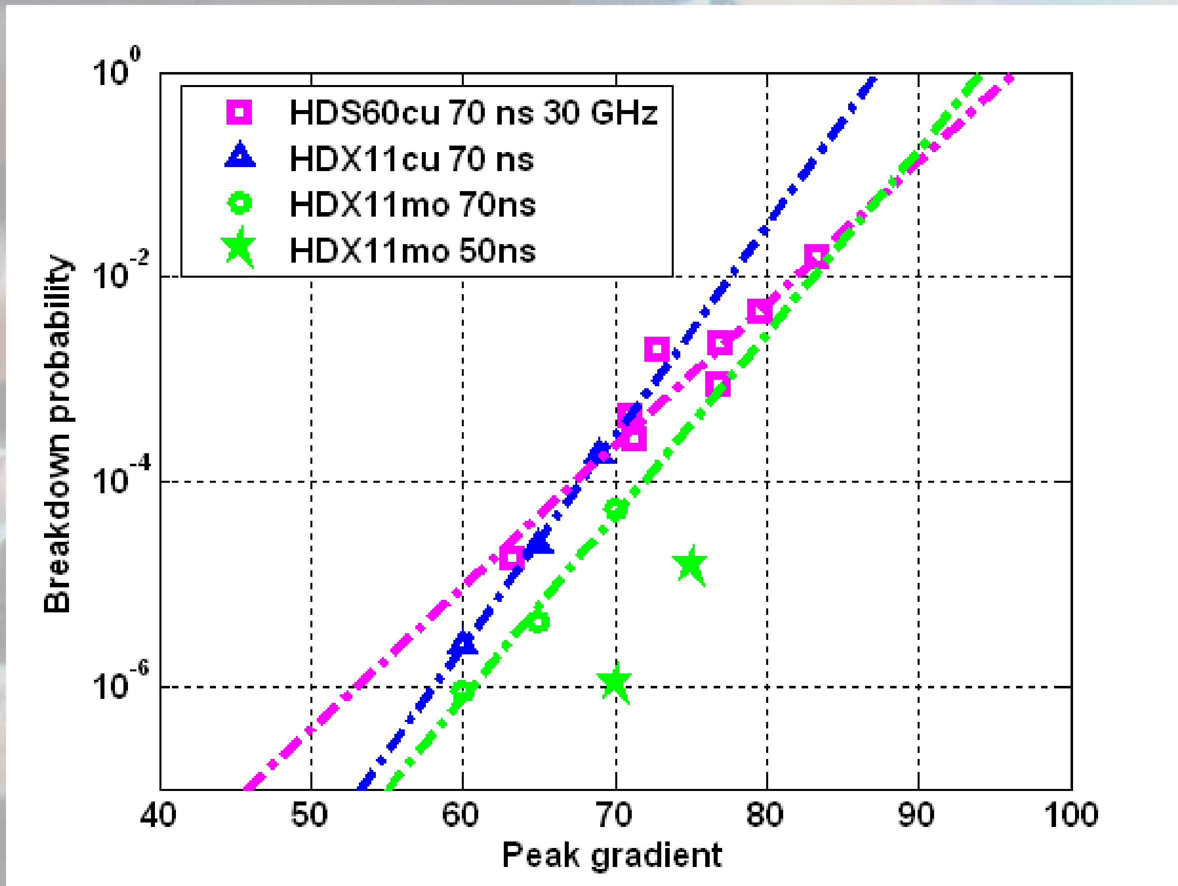
CTF3 High-Power test results – 30 GHz

More recent results & open questions:

- HDS geometry tested (Cu) – worse performance (many potential explanations)
- Breakdown rate slope for Mo less steep than Cu – material or clamping dependent ?
- Mo slope & conditioning limit not consistent in different tests…

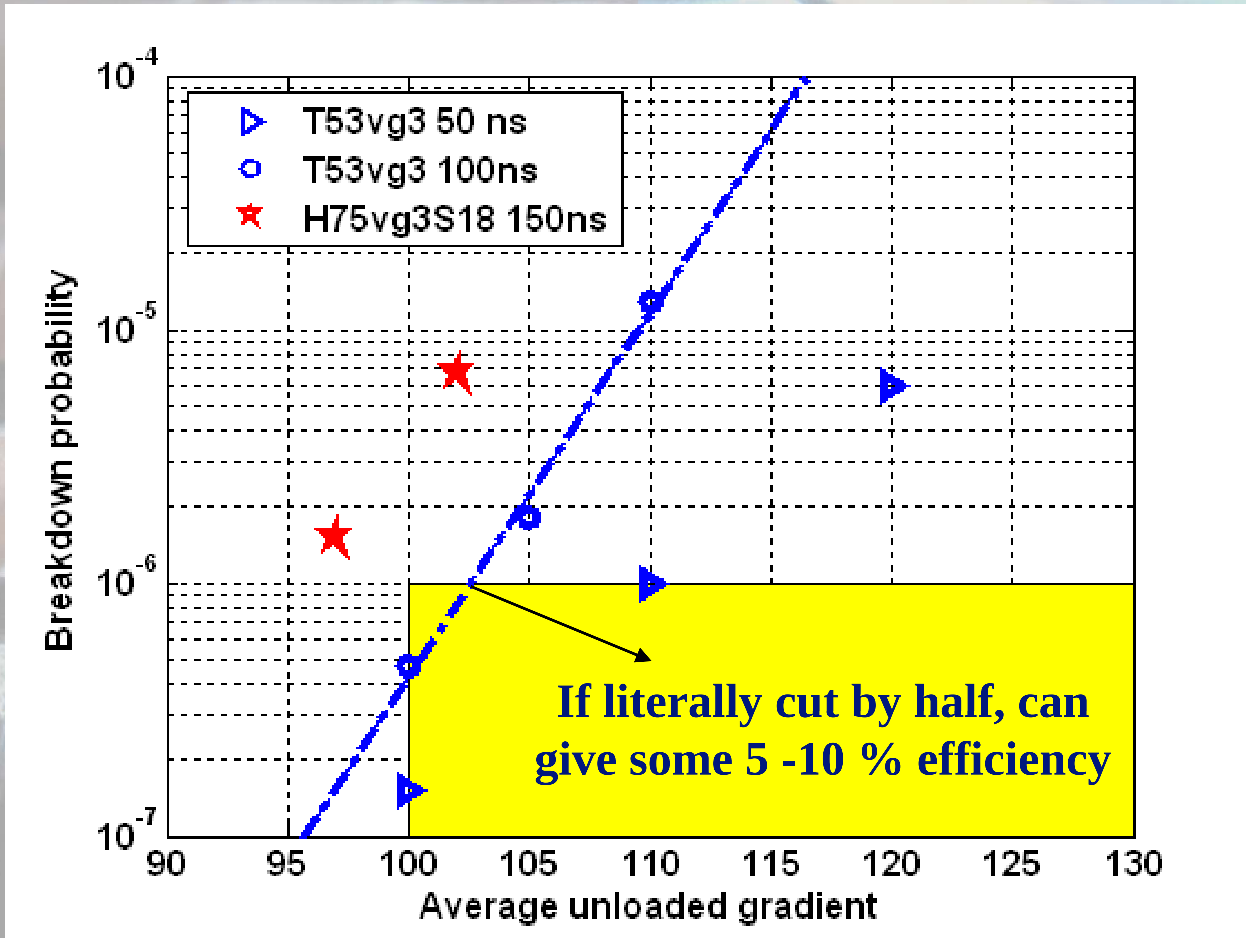


CTF3 - SLAC High-Power test results – 30 and 11.4 GHz
Scaled structures have the same gradient…



…fundamental assumption of structure optimization process, and of 12 GHz choice

12 GHz results – T53 performance indeed relevant for CLIC – energy reach vs efficiency



R1.2: Validation of drive beam generation scheme with fully loaded linac operation

The validation of the drive beam generation with a fully loaded linac is foreseen in CTF3.
Beam dynamics issues and achieving the overall efficiency look challenging.

R2.2: Validation of stability and losses of DB decelerator; Design of machine protection system

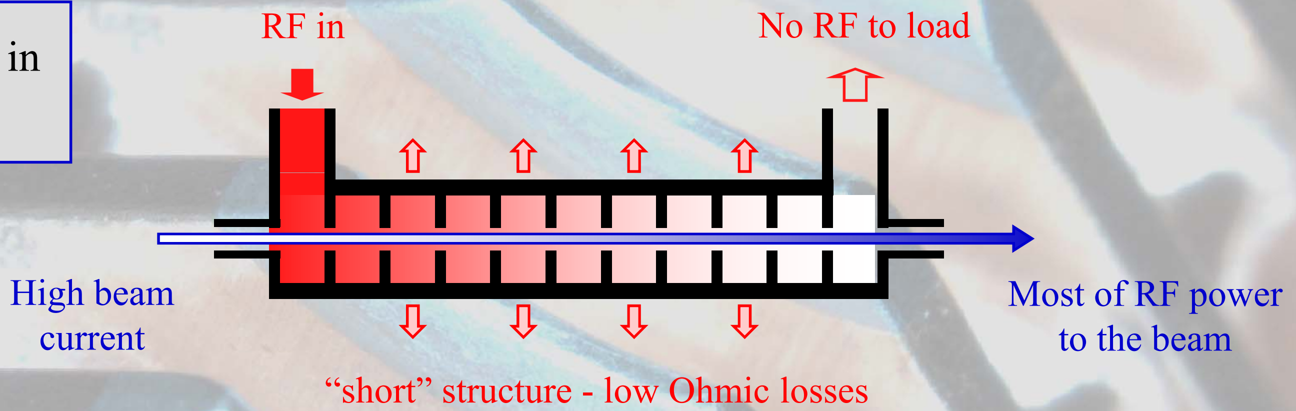
The very high power of the drive beam and its stability are serious concerns for CLIC. The drive beam stability should be validated, and the drive beam Machine Protection System, which is likely to be a complex system, should be designed to protect the decelerator structures.

R2.3: Test of relevant linac sub-unit with beam

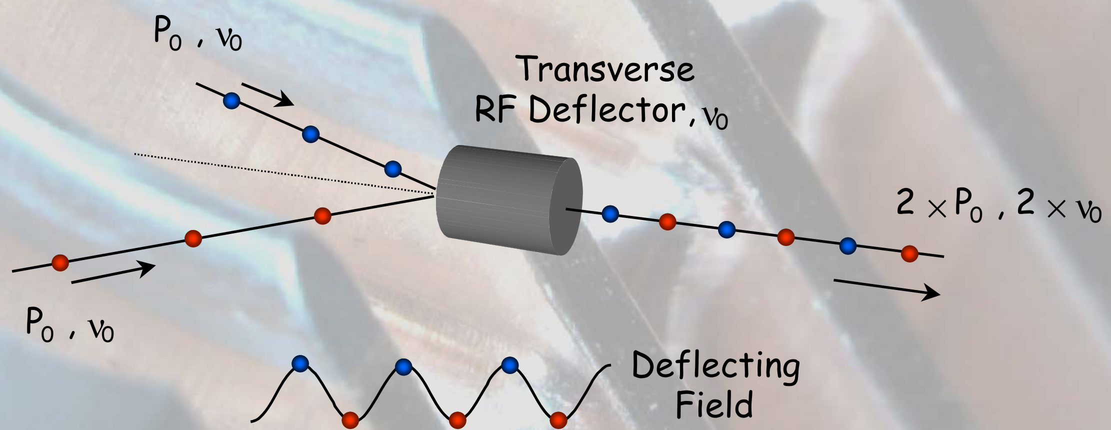
The test of a relevant linac subunit with beam is required. This is one of the purposes of CTF3, which should start operation in 2004.

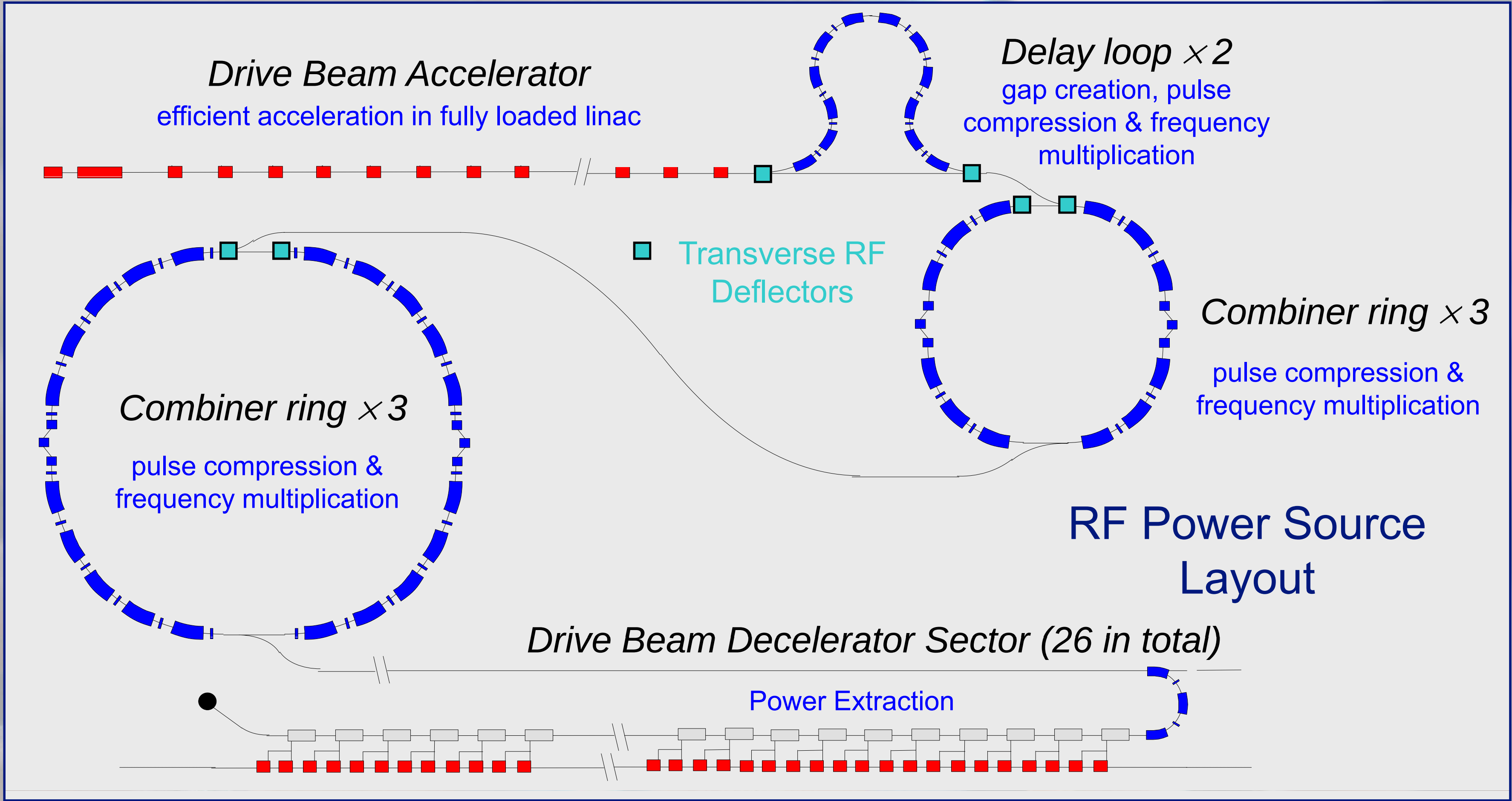
RF Power Source "building blocks"

Full beam-loading acceleration in TW sections

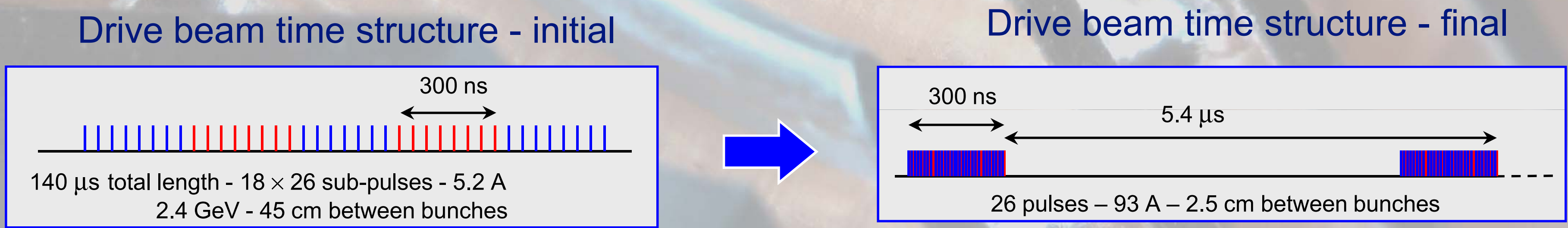


Beam combination/separation by transverse RF deflectors

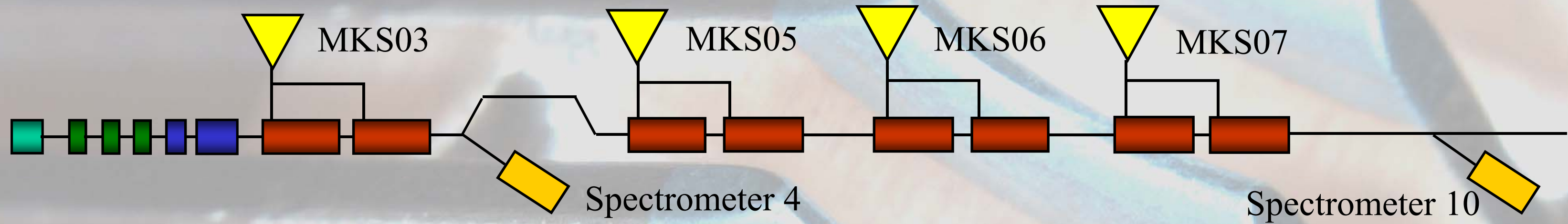




RF Power Source Layout

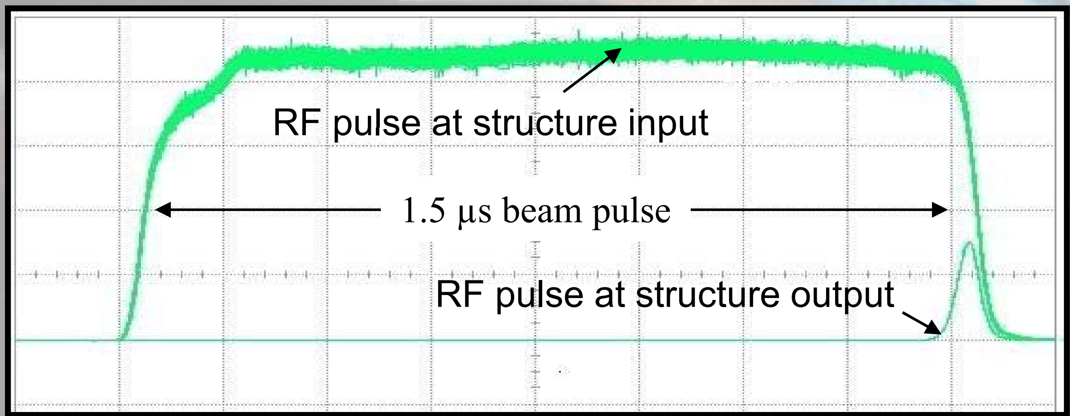


Demonstration at CTF3:



Setup: no RF pulse compression (with exception of MKS03)
1.5 μs long RF & beam pulses
adjust RF power, beam current and phase to fulfill fully loaded condition
measure energy gains for different klystrons

analog signal



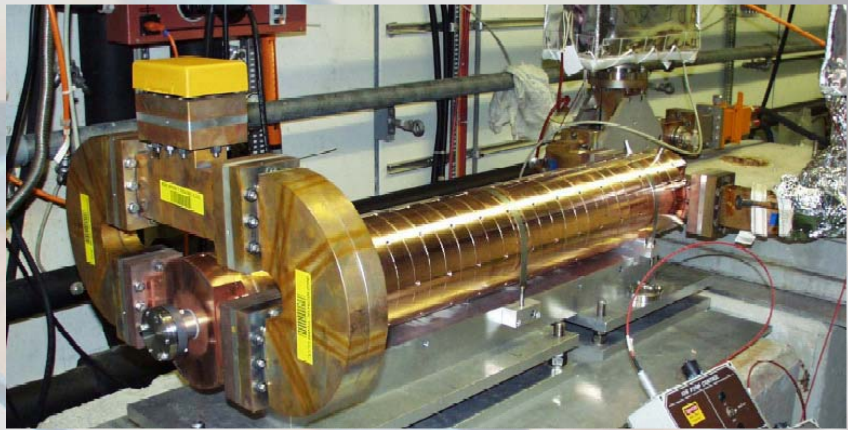
Measured RF-to-beam efficiency

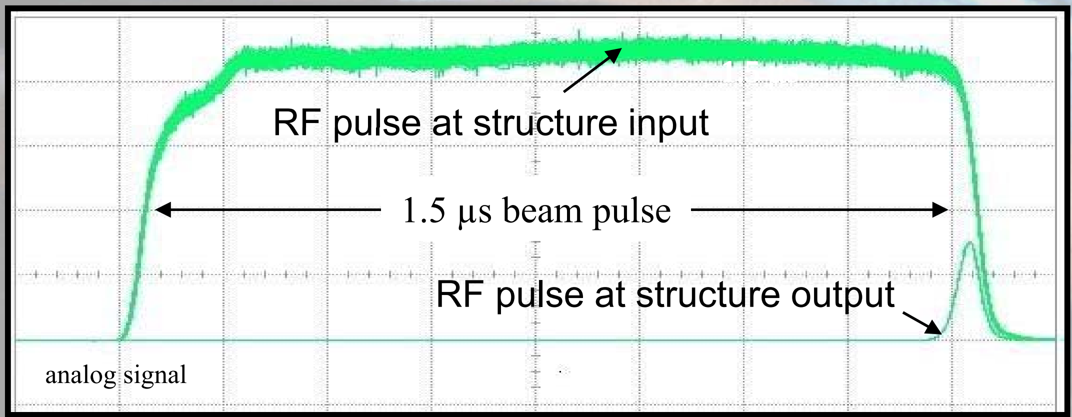
95.3 %

Theory

96% (~ 4 % ohmic losses)

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



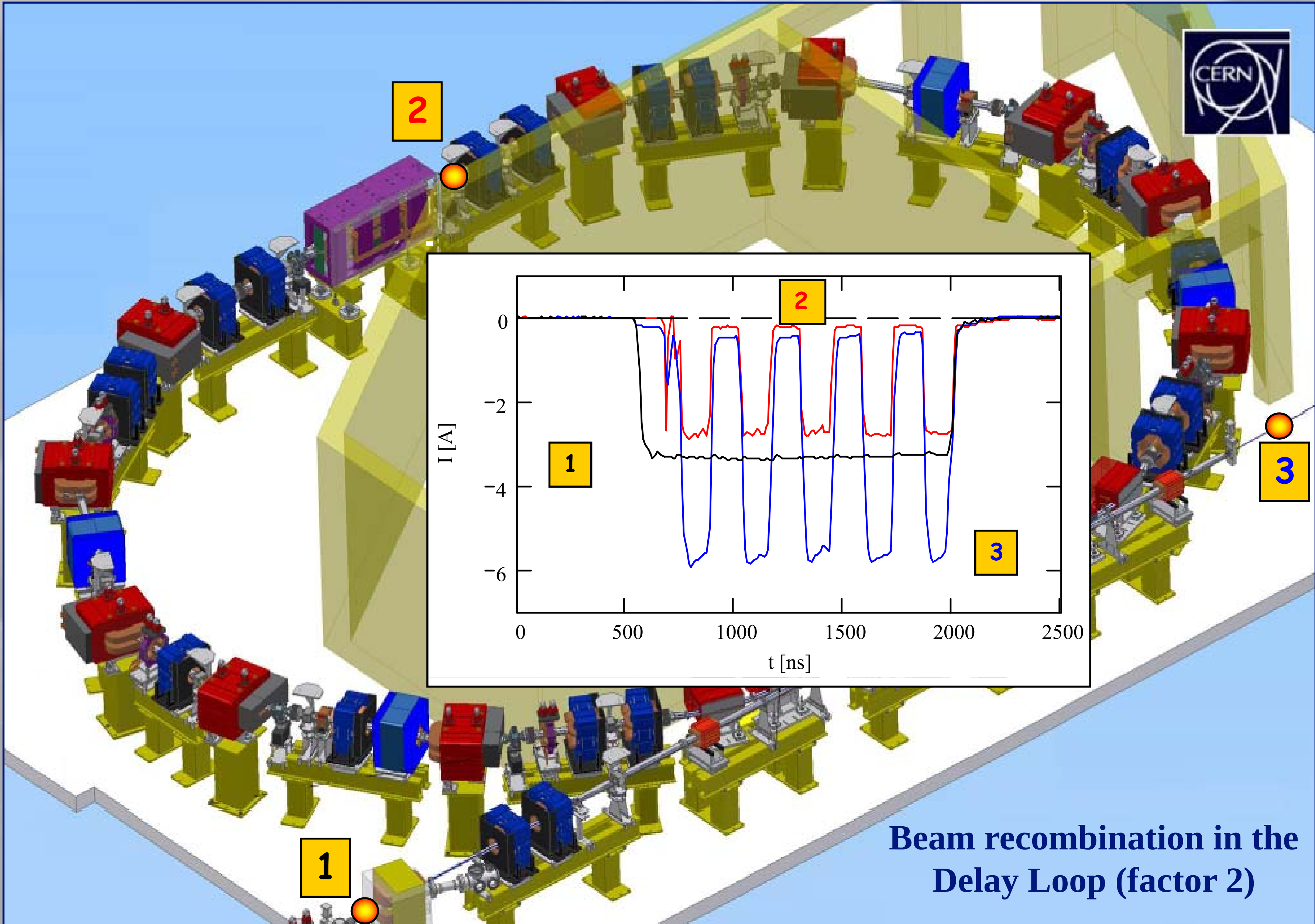


Measured RF-to-beam efficiency

95.3 %

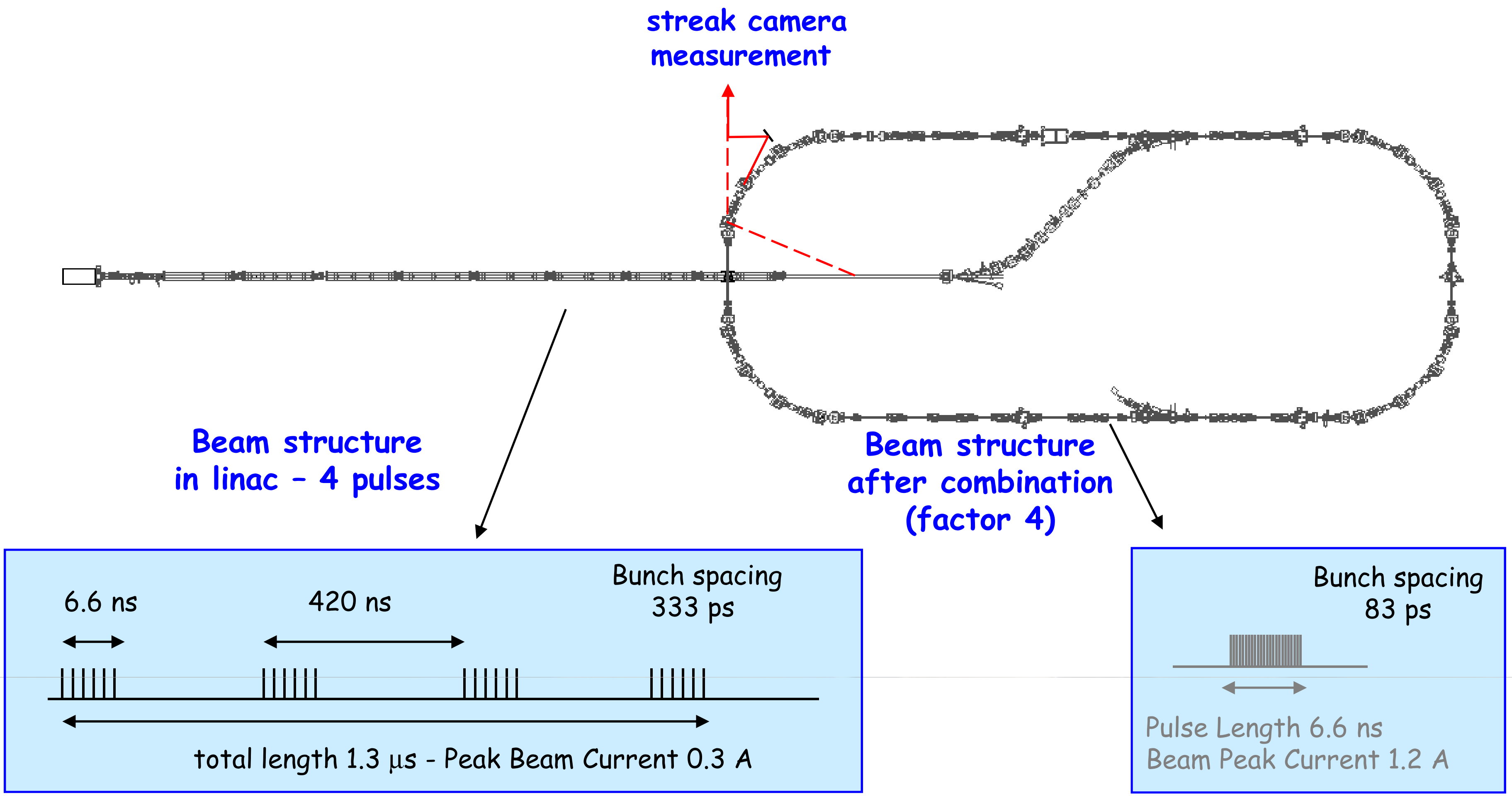
Theory

96% (~ 4 % ohmic losses)

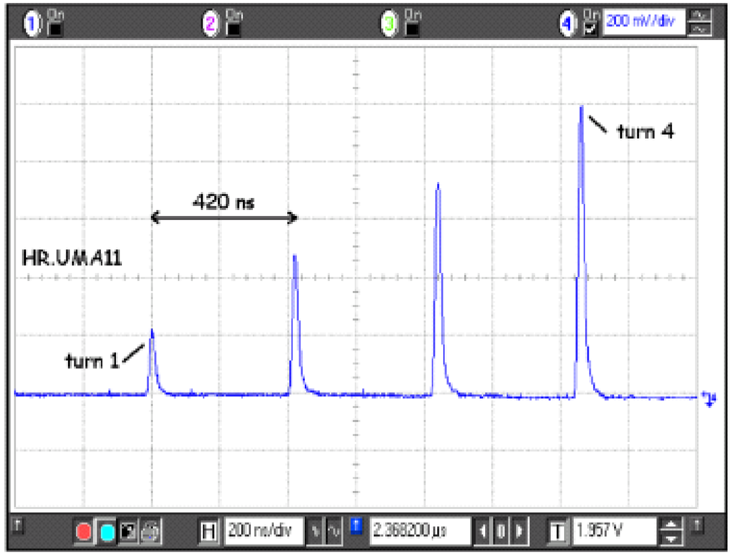


Beam recombination in the Delay Loop (factor 2)

CTF3 Preliminary Phase (2001-2002)

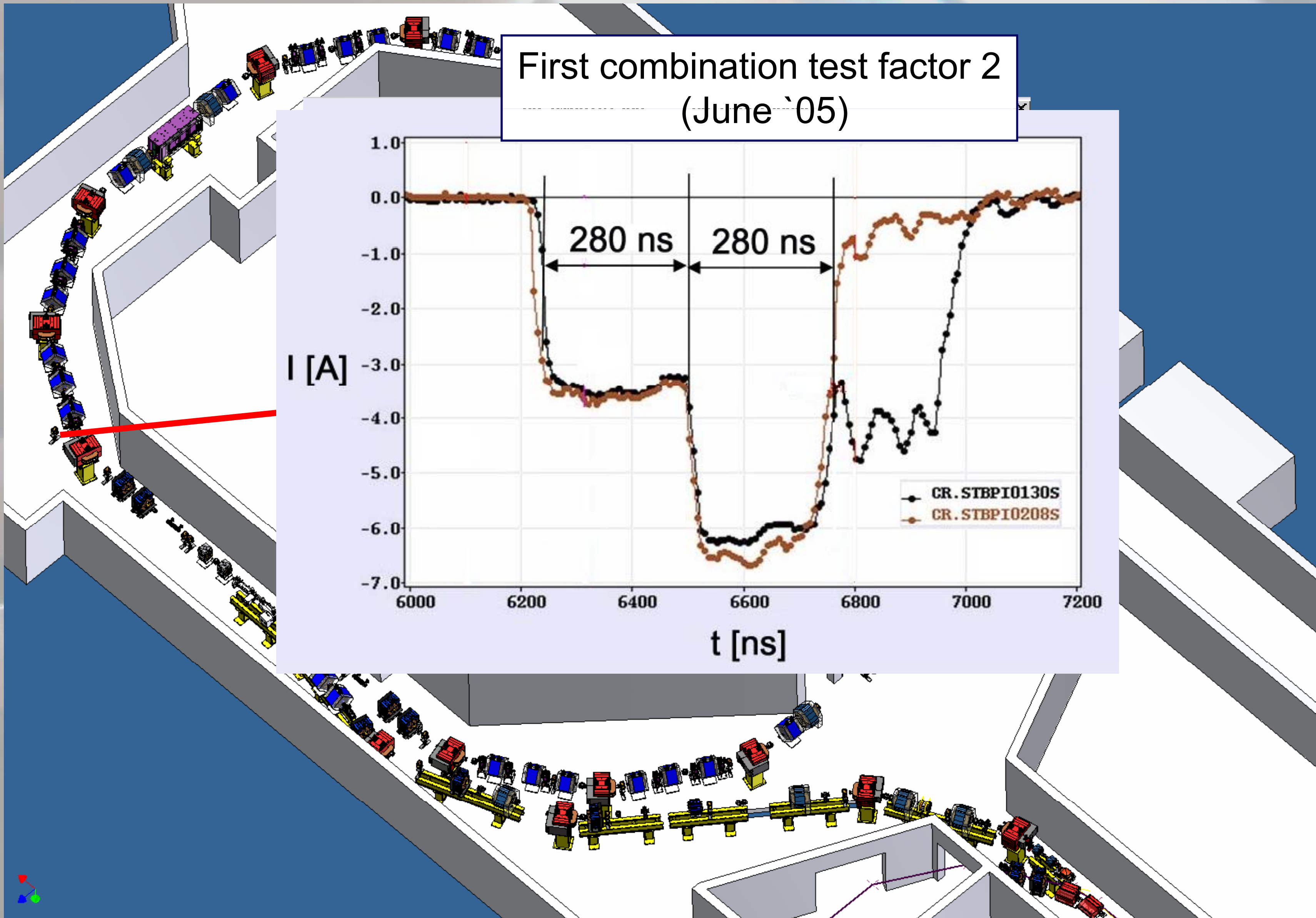


Preliminary Phase results
Bunch combination (factor 4)



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

Present status of combiner ring

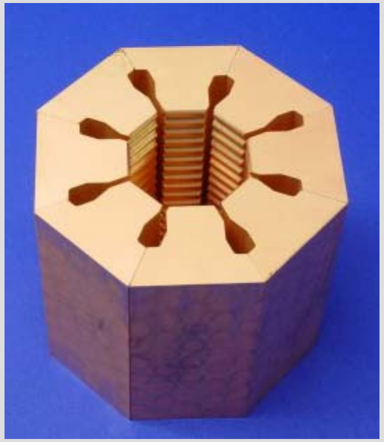


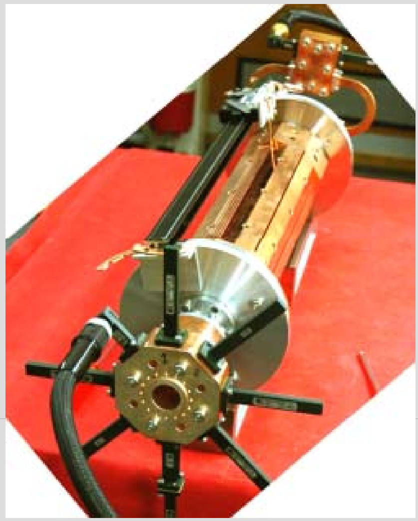
R1.3: Design and test of damped ON/OFF power extraction structure

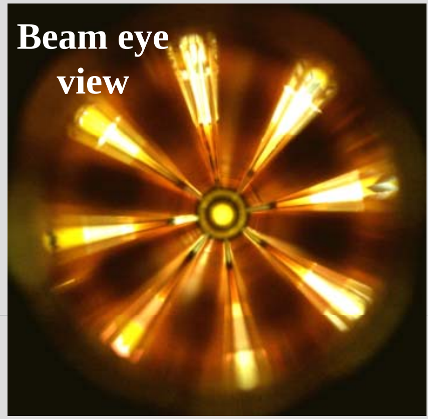
In the present CLIC design, an entire drive beam section must be turned off on any fault (in particular on any cavity fault). CLIC needs to develop a mechanism to turn off only a few structures in the event of a fault. At the time of writing this report, there is no specific R&D program aimed at that objective but possible schemes are being studied.

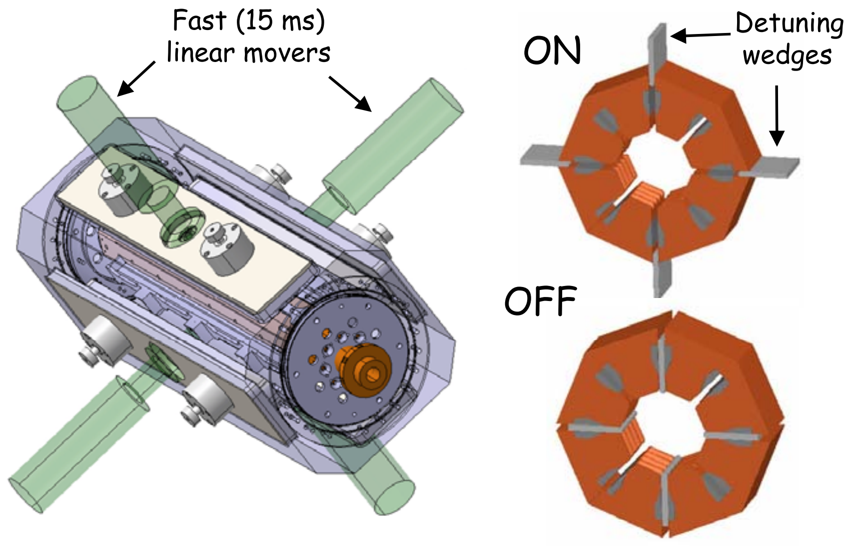
Power Extraction & Transfer Structure

- In interaction with the drive beam, the PETS must produce and efficiently extract a few hundreds MW of RF power.
- The PETS is a periodically corrugated structure with low impedance (big a/λ).

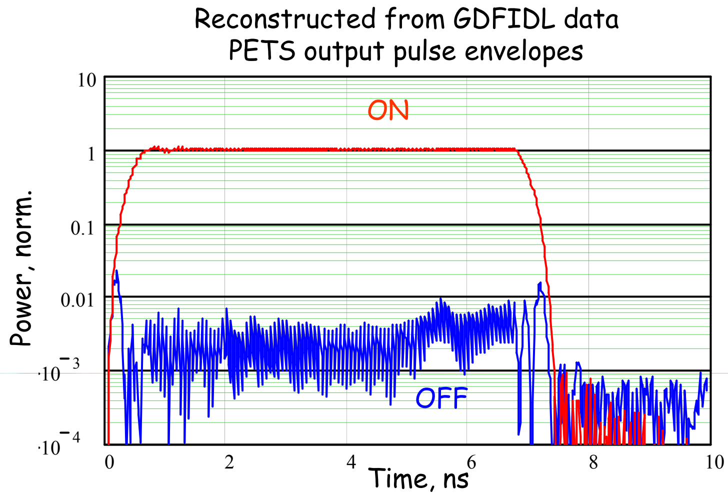


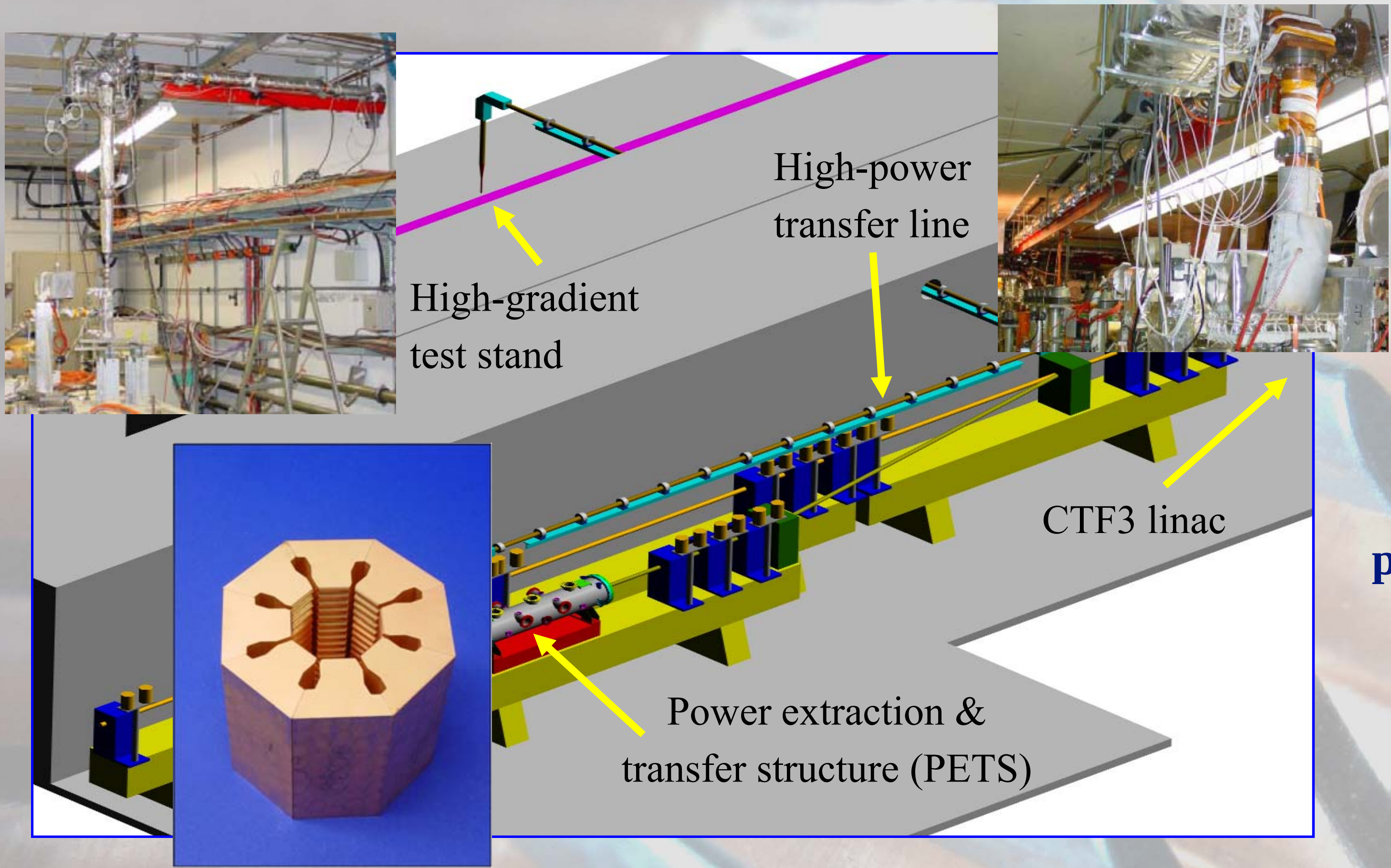






PETS ON/OFF mechanism



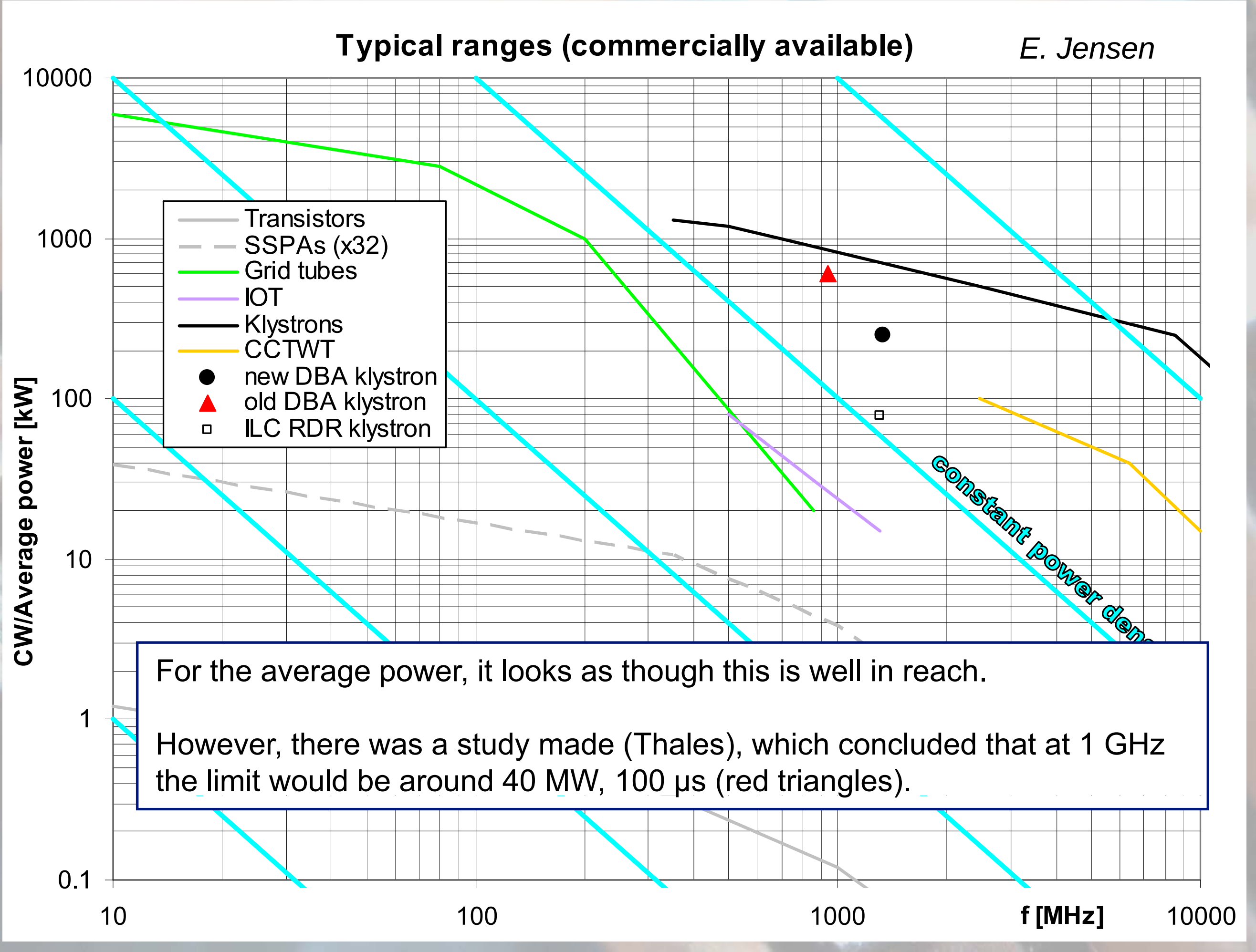


30 GHz power production in CTF3

- Produced power up to about 100 MW - structure tests started in 2005
- 5 structures tested until now

R2.5: Validation of drive beam 40 MW, 937 MHz Multi-Beam Klystron with long RF pulse

The validation of the proposed multibeam klystron performance is needed to finalize the design choices for the CLIC drive beam generation. This applies particularly to the 3 TeV energy upgrade (long pulse).



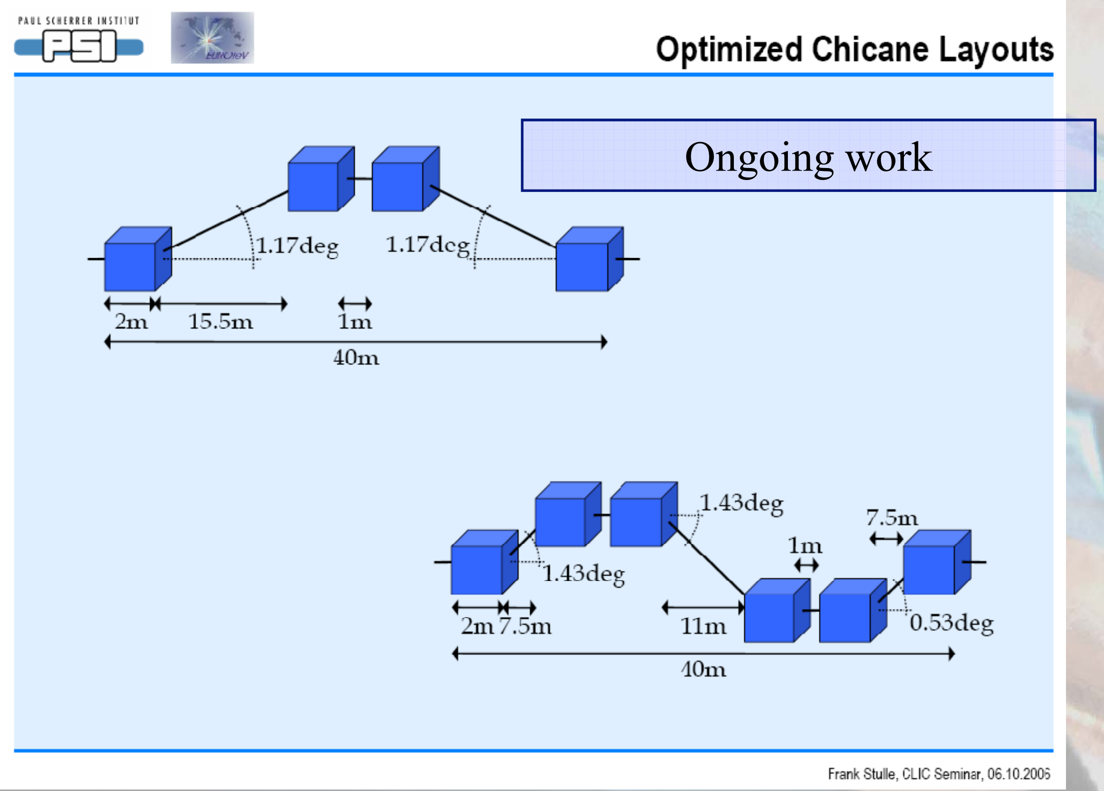
For the average power, it looks as though this is well in reach.

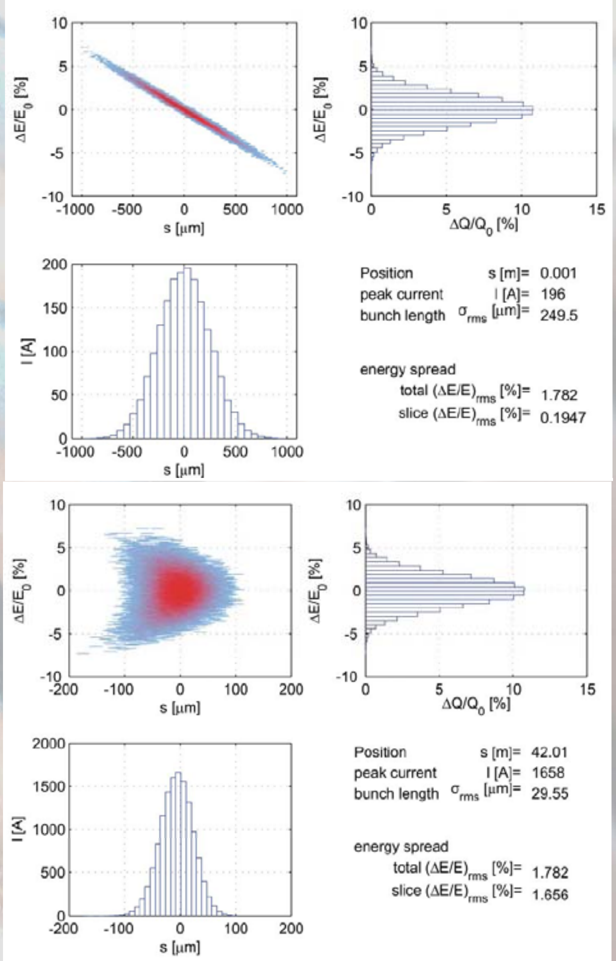
However, there was a study made (Thales), which concluded that at 1 GHz the limit would be around 40 MW, 100 μs (red triangles).

R2.5: Effects of coherent synchrotron radiation in bunch compressors

Calculations of the effects of coherent synchrotron radiation on the CLIC bunch compressors must be performed.

F. Stulle -PSI





R2.6: Design of an extraction line for 3 TeV c.m.

An extraction line design for 3 TeV c.m. must be developed.

Promising first design

A. Ferrari

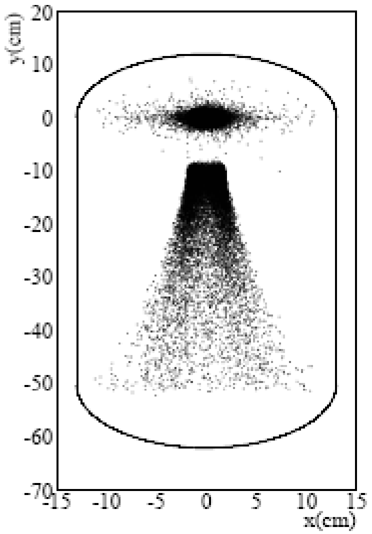


Figure 18: Transverse beam profiles obtained at the dump window, 247 m downstream of the interaction point.

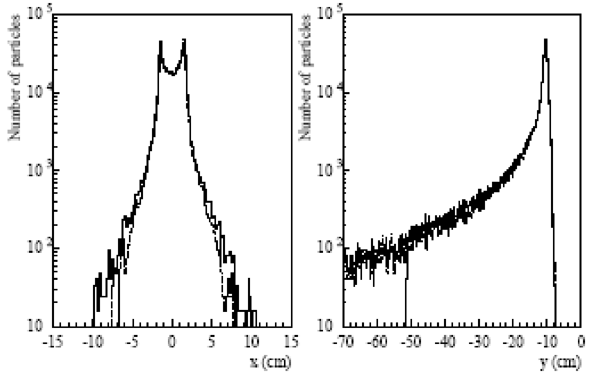


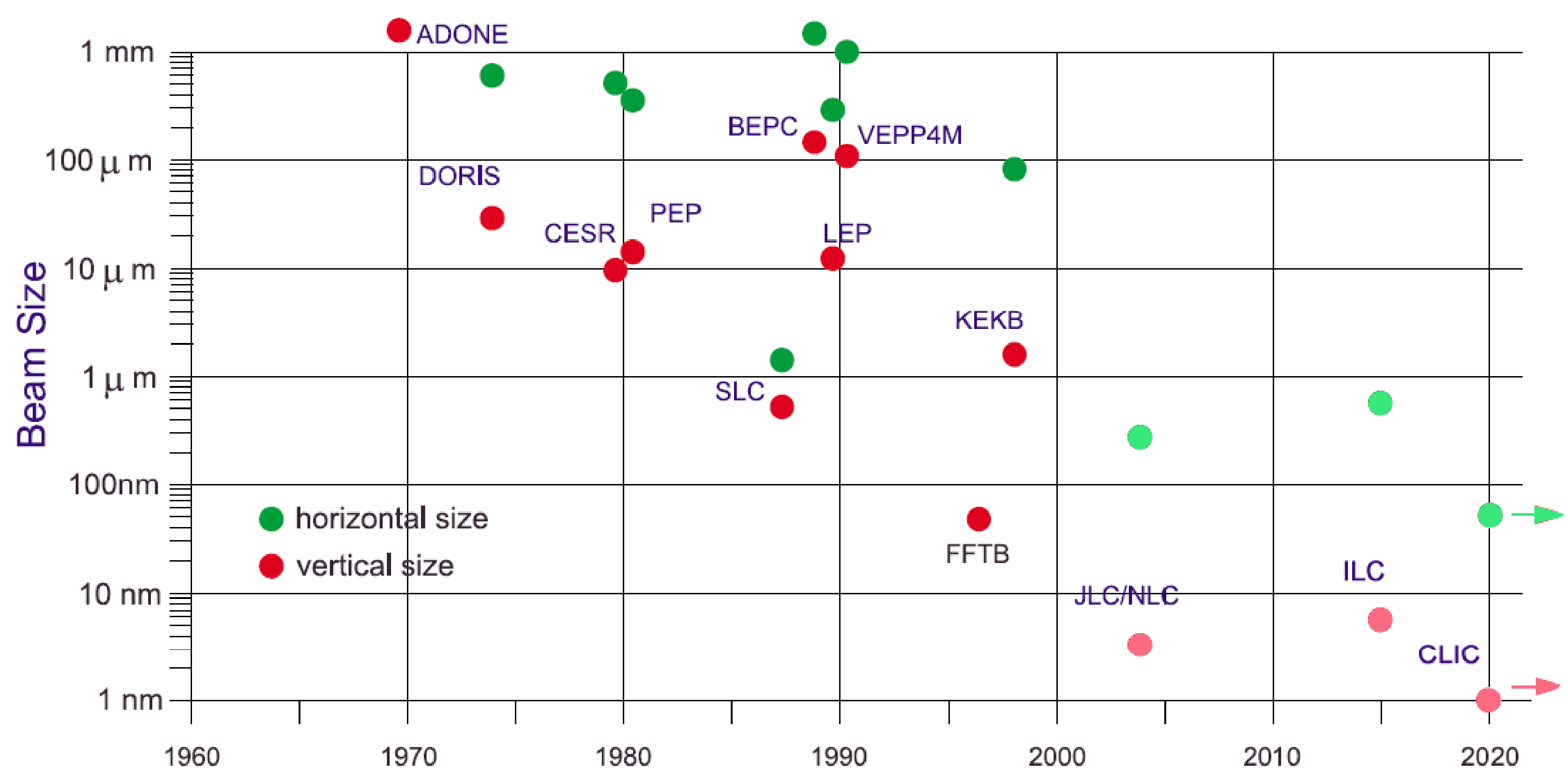
Figure 17: Horizontal and vertical profiles of the disrupted beam and the particles of the coherent pairs with the same charge, at the end of the CLIC post-collision line: the full (respectively dashed) line spectra are obtained with (respectively without) vertically focusing elements downstream of the chicane. At first order, the horizontal beam profile gives an image of the x' distribution at the interaction point, while the vertical beam profile shows the energy spectrum of the disrupted beam.

Other (non ILC-TRC) issues

Low emittance generation – damping ring

→ **HANS....**

The small beam size challenge



Adapded from S. Chattopadhyay, K. Yokoya, Proc. Nanobeam `02

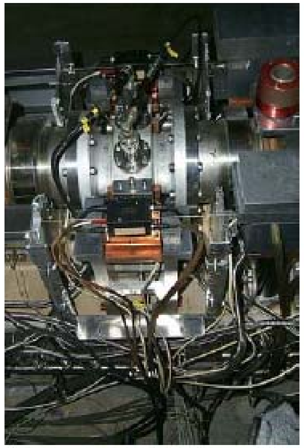
ALIGNMENT SYSTEMS

Tolerance of CLIC prealignment: ± 10 μm over 200m

→ need for alignment systems with the following characteristics:

- high resolution
- continuous measurements
- working in severe environment (strong electro-magnetic fields and radiations)

Hydrostatic Levelling System (HLS)



Wire Positioning System (WPS)

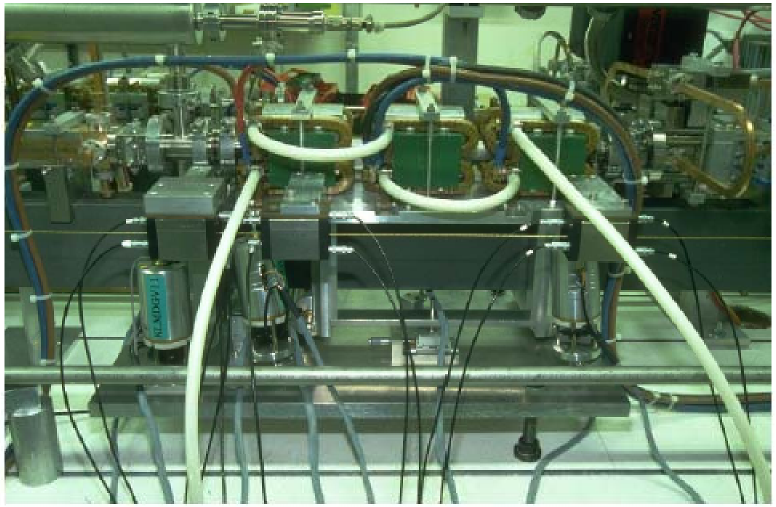
Red Alignment System from NIKHEF (RASNIK)

H. Mainaud

ALIGNMENT SYSTEMS : PREVIOUS APPLICATIONS

All these alignment systems have already been used sucessfully :

- ✓ L3 detector for RASNIK system
- ✓ LEP low beta quadrupoles for HLS system
- ✓ LEP spectrometer for WPS system
- ✓ WPS + HLS tested on CTF2



deviation of the vertical: 15″ at CERN

For CLIC: a new parameter … the dimension
Perturbation of gravity and its consequences

H. Mainaud

Stability

S. Redaelli et al.

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

CERN vibration test stand

Main/Drive Beam Phase stability

The Impact of Longitudinal Drive Beam Jitter on the CLIC Luminosity

CLIC Note 598

D. Schulte, E. J. N. Wilson, F. Zimmermann

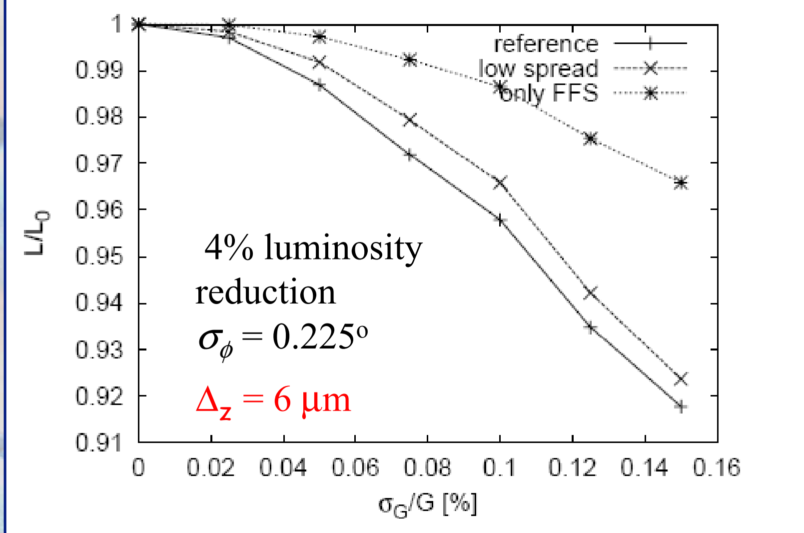
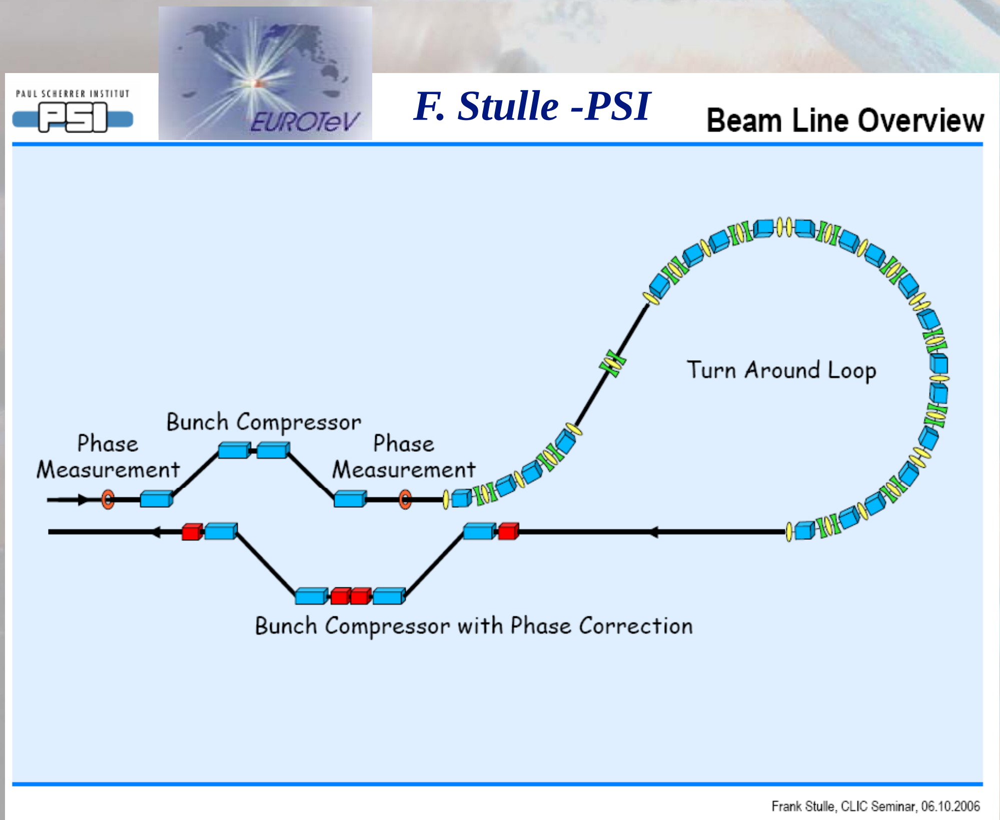
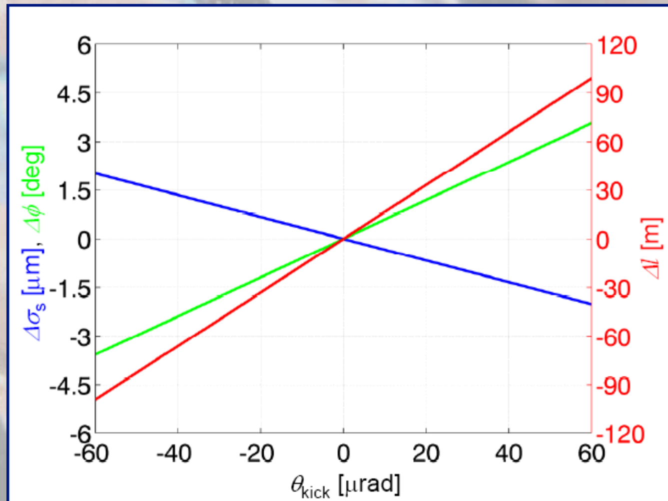


Figure 1: The relative luminosity as a function of a coherent gradient error in the main linac.

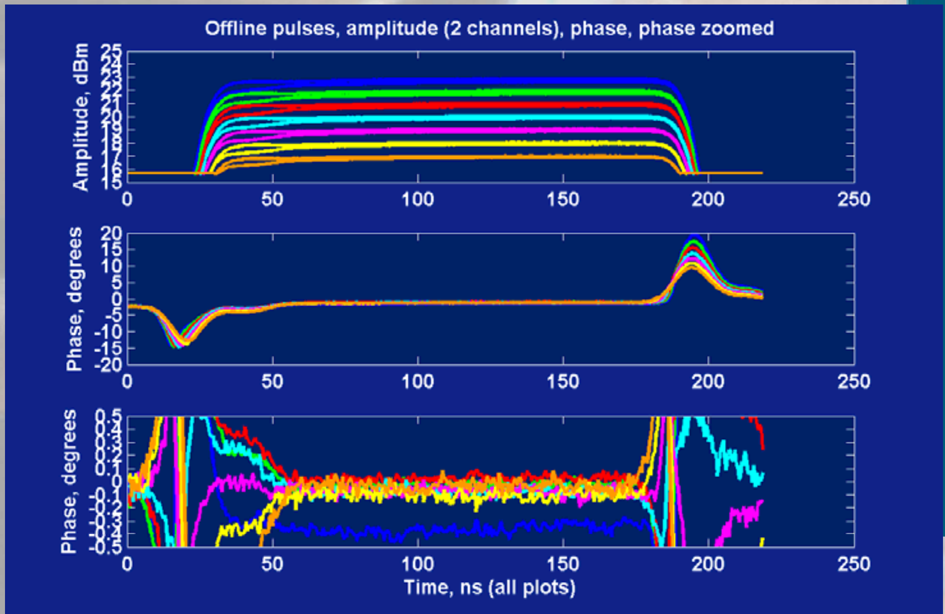


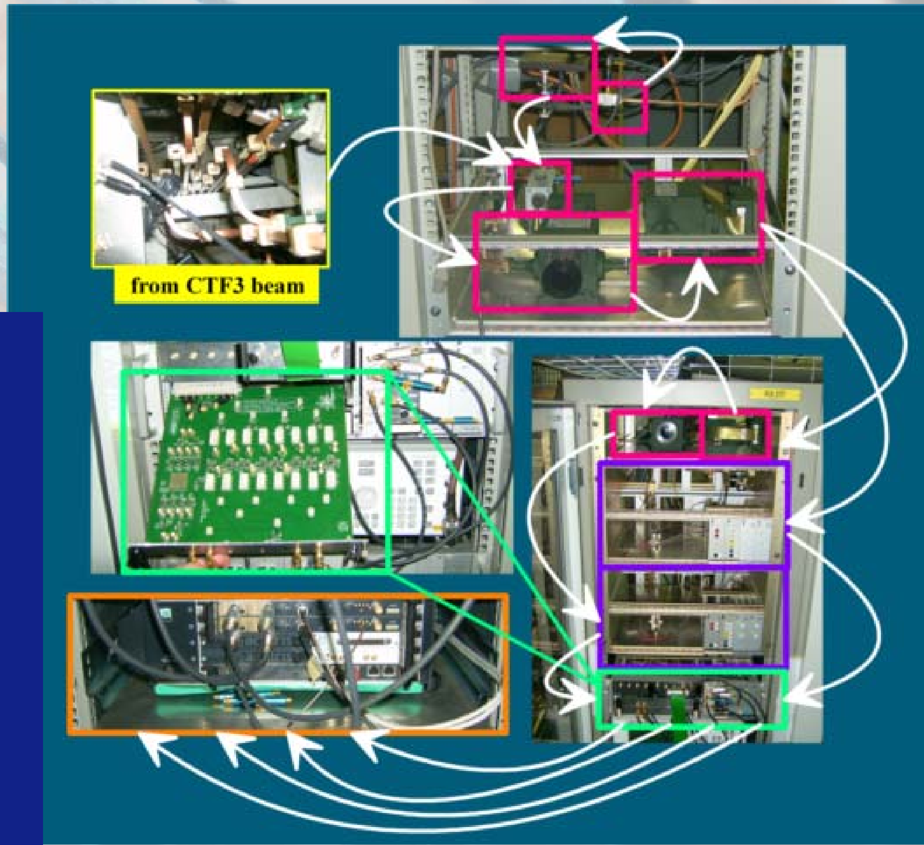


Diagnostics
Phase measurement

J. Sladen, A. Andersson

- Phase accuracy: 0.1º
- Amplitude range: ~6dB
- Bandwidth: 50MHz, system investigated up to 250MHz





Diagnostics
Beam position

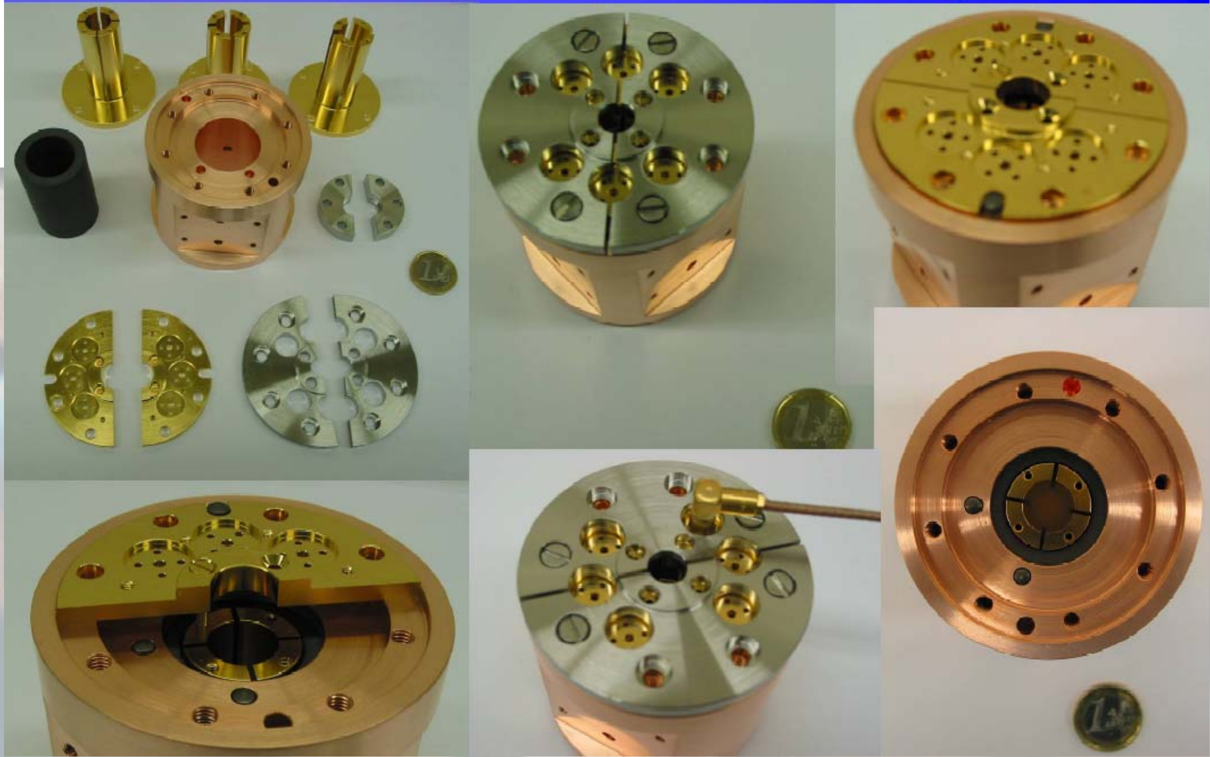
Goal

L Soby – I. Podadera

Measurement of the beam position and current in the main linac (attached to the quadrupoles) of the next generation colliders (ILC and CLIC) with the specifications:

- **R**esolution:100 nm.
- **A**perture: 4-6 mm.
- **A**bsolute precision: 10 μm.
- **R**ise time: 15 ns.

Preliminary assembly



Test in CTF3 late this year

L Soby – A. D'Elia

The aim

The 3rd generation of CLIC Test Facility (CTF3) foresees a beam formed by bunches separated of

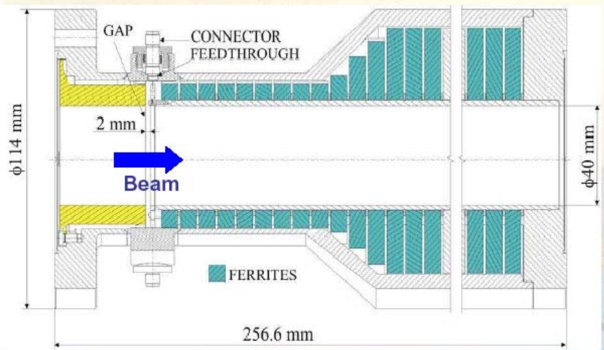
Δ_b = 67 ps ⟶ WCM h. f. cut-off = 20 GHz

for a total pulse duration of

τ_r = 1.54 μs ⟶ WCM l. f. cut-off = 100 kHz

Diagnostics
Wall Current Monitor

The existing design



The existing design is based on a previous design for the CTF2
(63 MHz ≤ bandwidth ≤ 10 GHz)
but

- Bigger volume of ferrite in order to lower the l. f. cut-off to 100 kHz
- The miniature feedthrough modified in order to extend their bandwidth beyond 20 GHz

Diagnostics - other issues

- Beam profile – main beam
- Emittance – main beam (for bumps)
- Beam profile drive beam
- Luminosity monitor
- ...

CONCLUSIONS

- 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
- (Some) remaining key issues clearly identified (ILC-TRC)
- CLIC technology related issues addressed in CTF3 by 2010
- Technology independent issues studied within EuroTeV and in close collaboration with ILC
- Other key issues, identified by the study, partly under study
- Plans to cover the rest → Hans

Still a lot of work before it flies…