Recent Progress at the CLIC Test Facility 3 at CERN

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Talk outline

- Introduction to the CLIC two-beam scheme
- The CLIC Test Facility CTF3
- Results from CTF3
    - Past
    - Recent Results
- Outlook on future activities
- Conclusions

CLIC aim:

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

Present mandate:

Demonstrate all key feasibility issues by 2010 (CTF3)

Motivation:

Aim to provide the High Energy Physics community with the feasibility of CLIC technology in due time, when physics needs will be fully determined following LHC results (2010?).

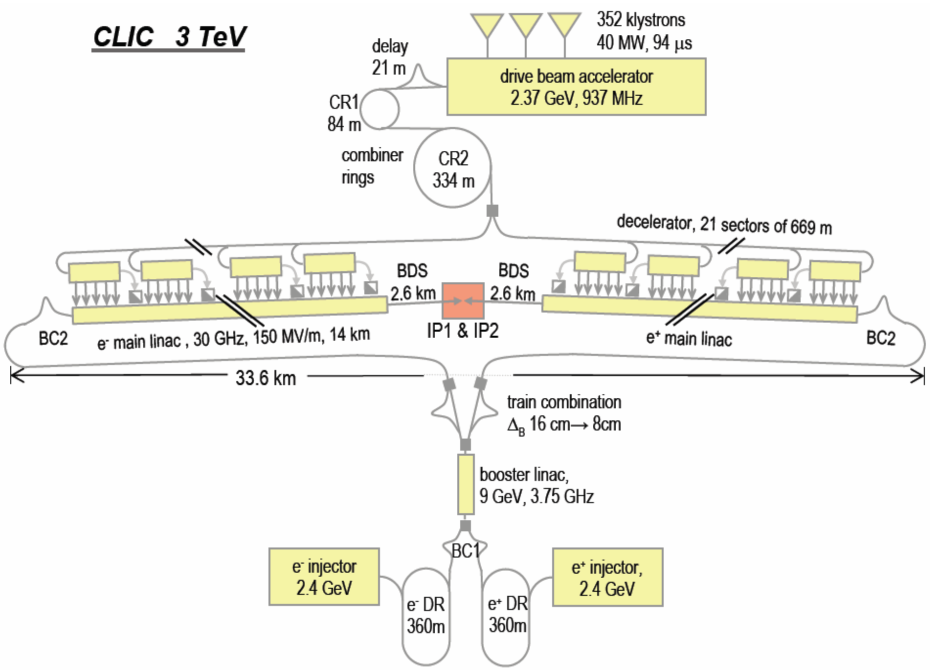
WORLD WIDE CLIC COLLABORATION

Ankara University (Turkey)
Berlin Tech. Univ. (Germany)
BINP (Russia)
CERN
CIEMAT (Spain)
DAPNIA/Saclay (France)
Department of Atomic Energy (India)
Finnish Industry (Finland)
Helsinki Institute of Physics (Finland)
IAP (Russia)
Instituto de Fisica Corpuscular (Spain)
INFN / LNF (Italy)
JASRI (Japan)
JINR (Russia)
KEK (Japan)
LAL/Orsay (France)
LAPP/ESIA (France)
LLBL/LBL (USA)
North-West. Univ. Illinois (USA)
Polytech. University of Catalonia (Spain)
RAL (England)
SLAC (USA)
Svedberg Laboratory (Sweden)
Uppsala University (Sweden)

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
Wall plug (RF) to main beam power efficiency	η_{tot}	10	%

Basic features of CLIC



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

- High acceleration gradient (150 MV/m)

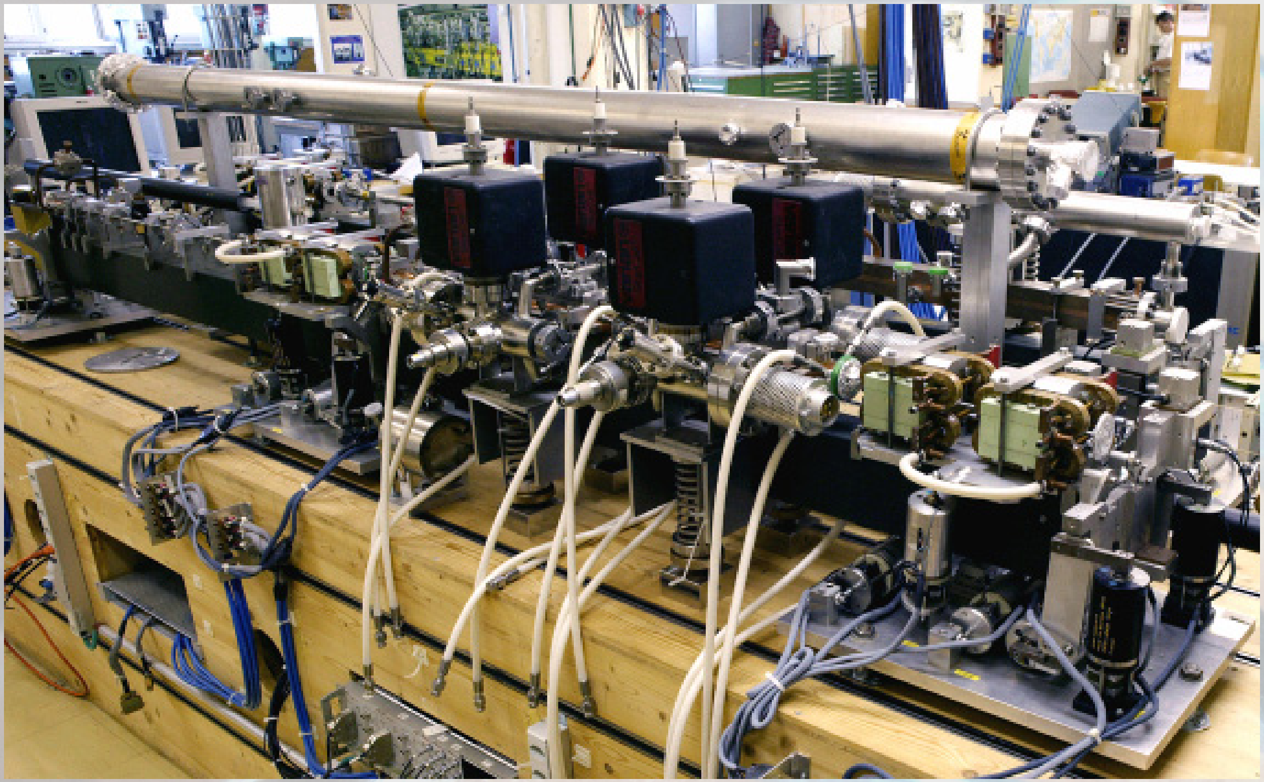
- “Compact” collider - overall length < 40 km
- Normal conducting accelerating structures
- High acceleration frequency (30 GHz)

- Two-Beam Acceleration Scheme

- Capable to reach high frequency
- Simple tunnel, no active elements

- Central injector complex

- “Modular” design, can be built in stages

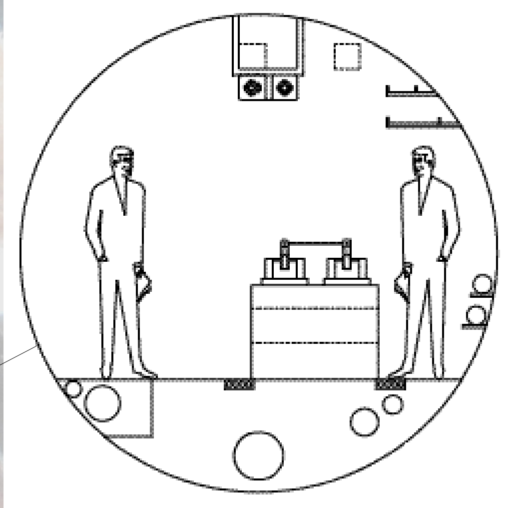


CLIC MODULE

(12000 modules at 3 TeV)

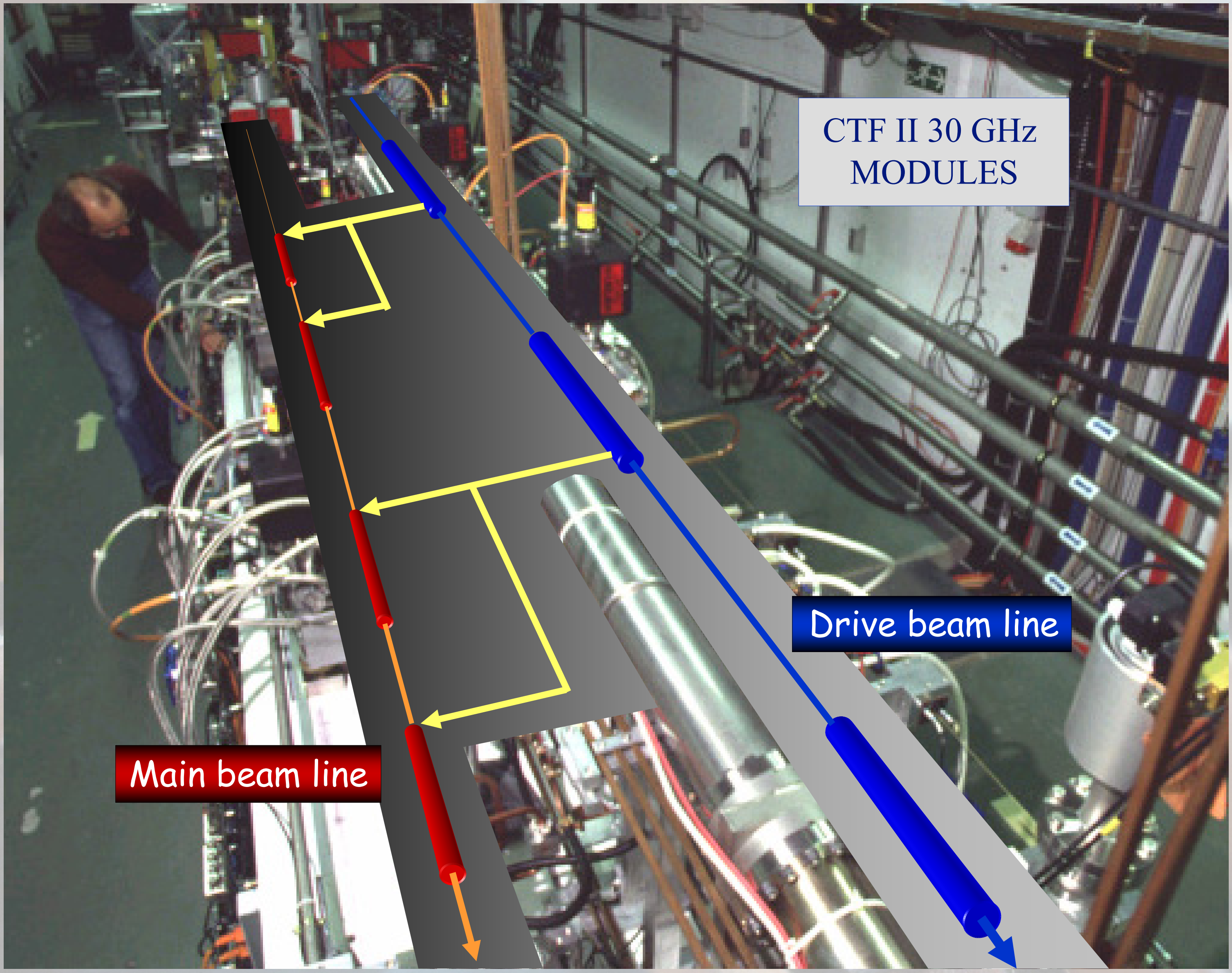
CLIC two-beam scheme

CLIC TUNNEL CROSS-SECTION

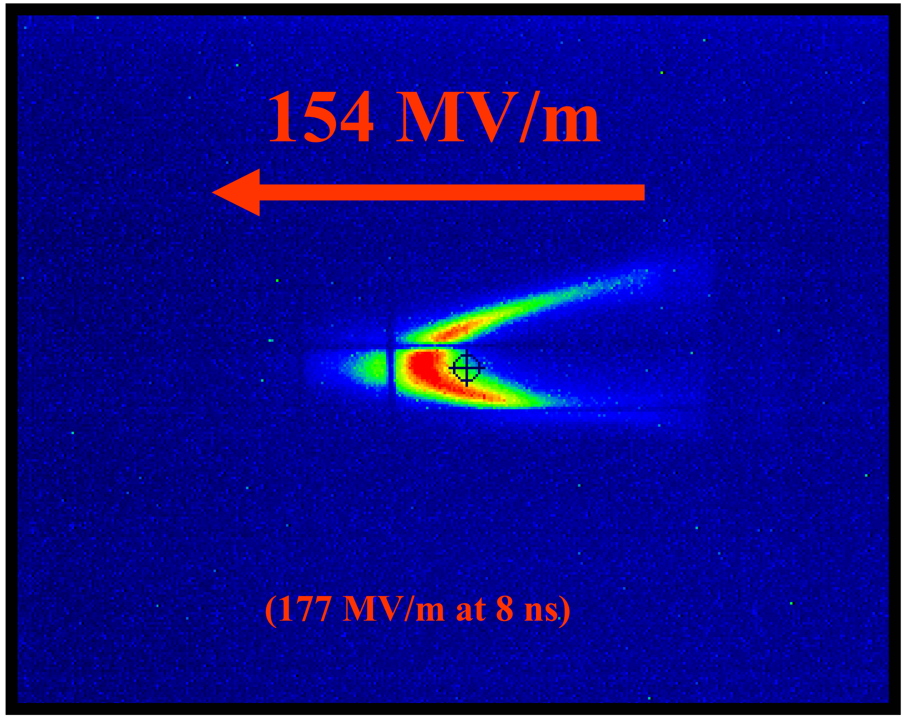


3.8 m diameter

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



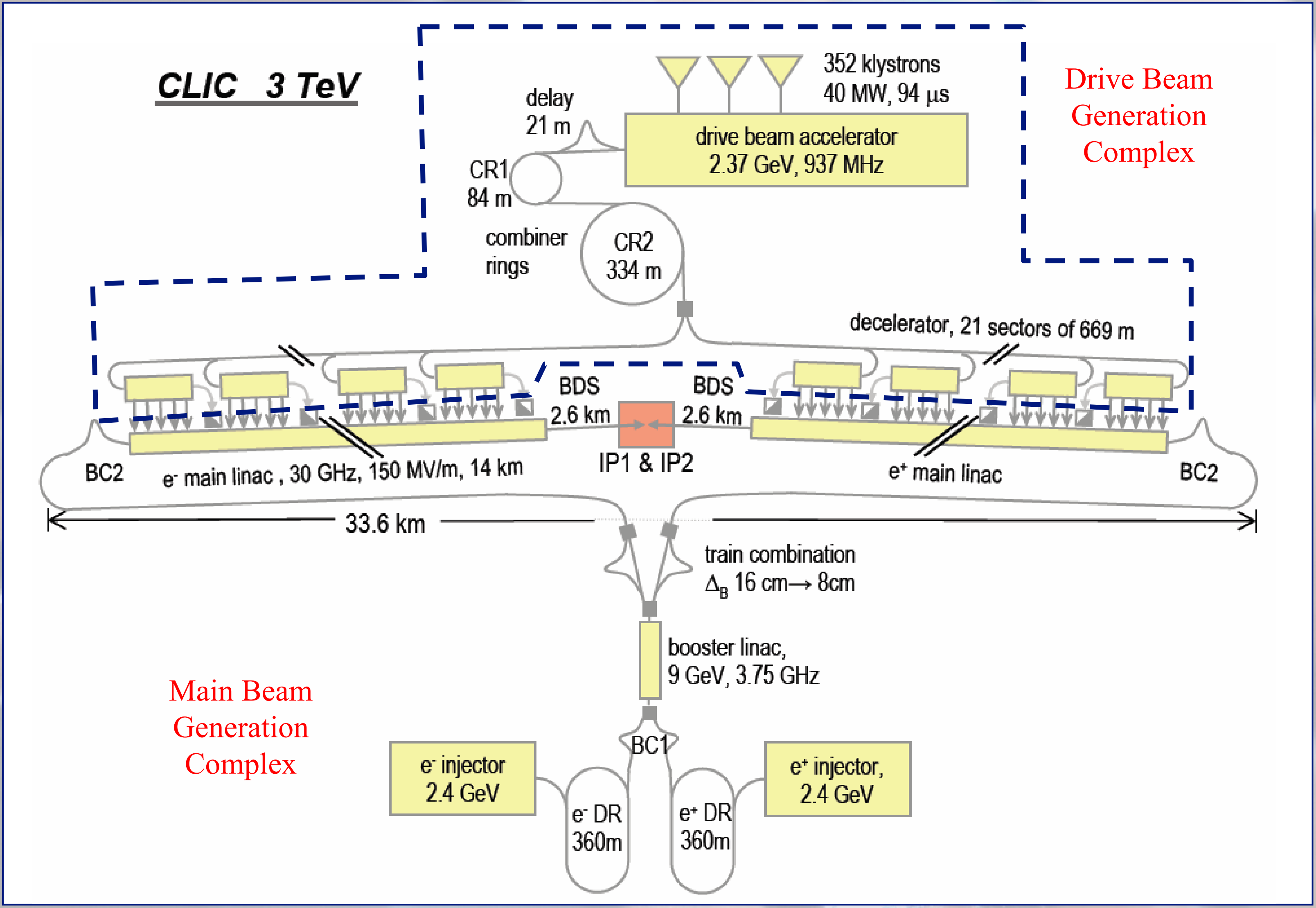
High-gradient tests in CTF II



A [illegible] LIC accelerating field requirements without any damage

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

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

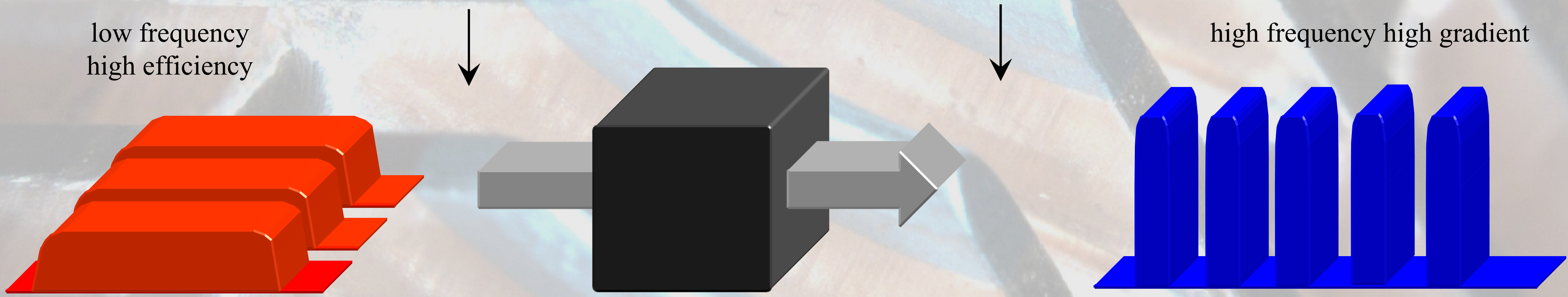
low frequency
high efficiency

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 , τ_0

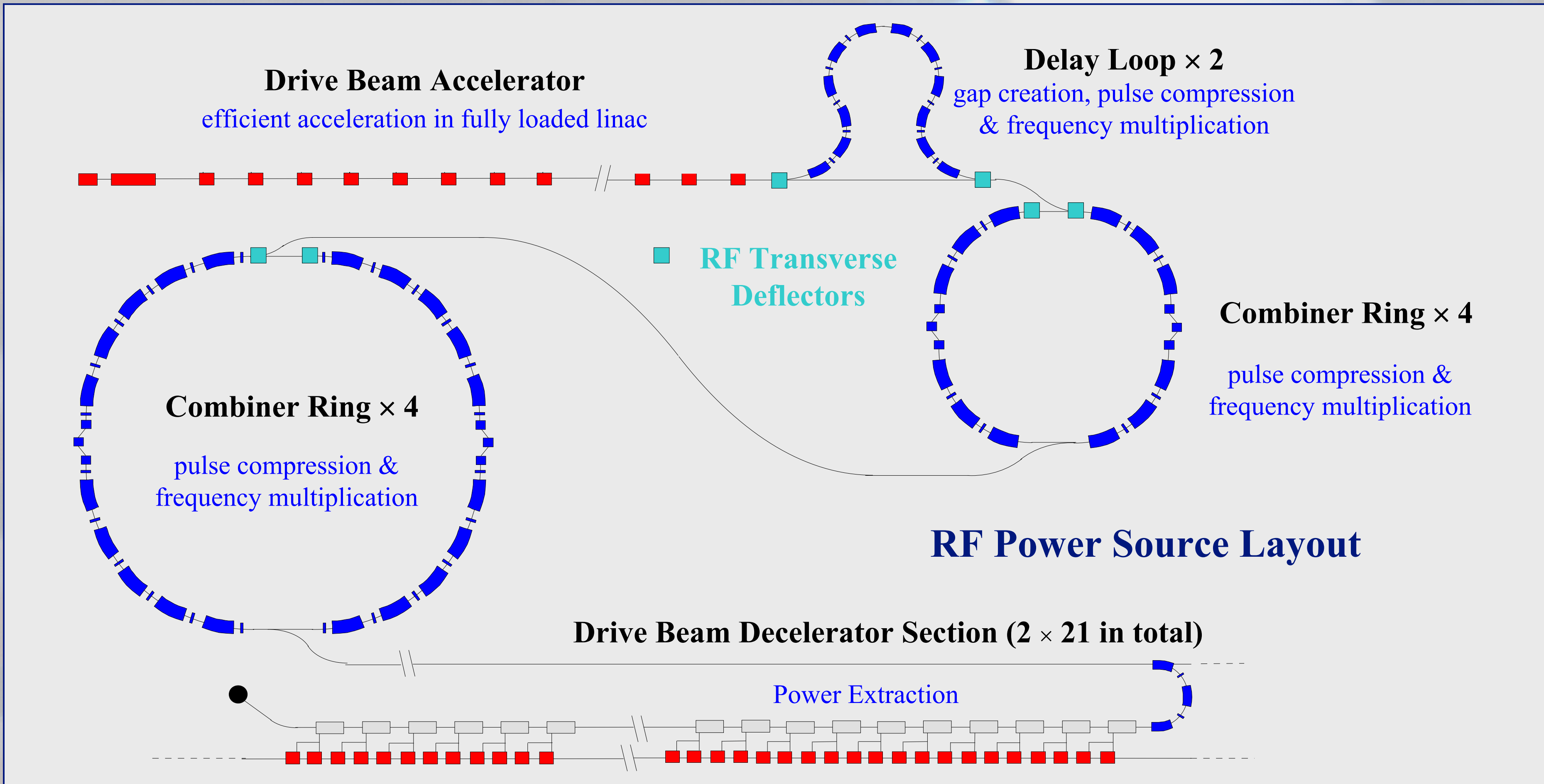
Electron beam
manipulation

Short RF Pulses

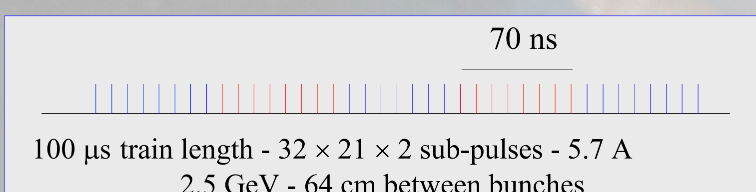
$P_A = P_0 \times N_1$

$\tau_A = t_0 / N_2$

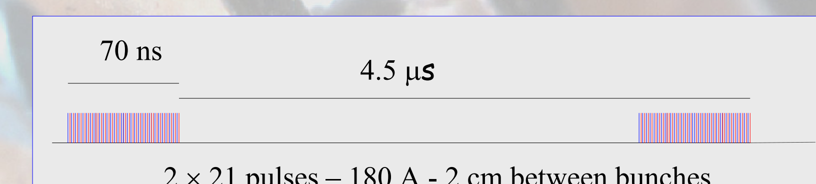
$\nu_A = \nu_0 \times N_3$



Drive beam time structure - initial

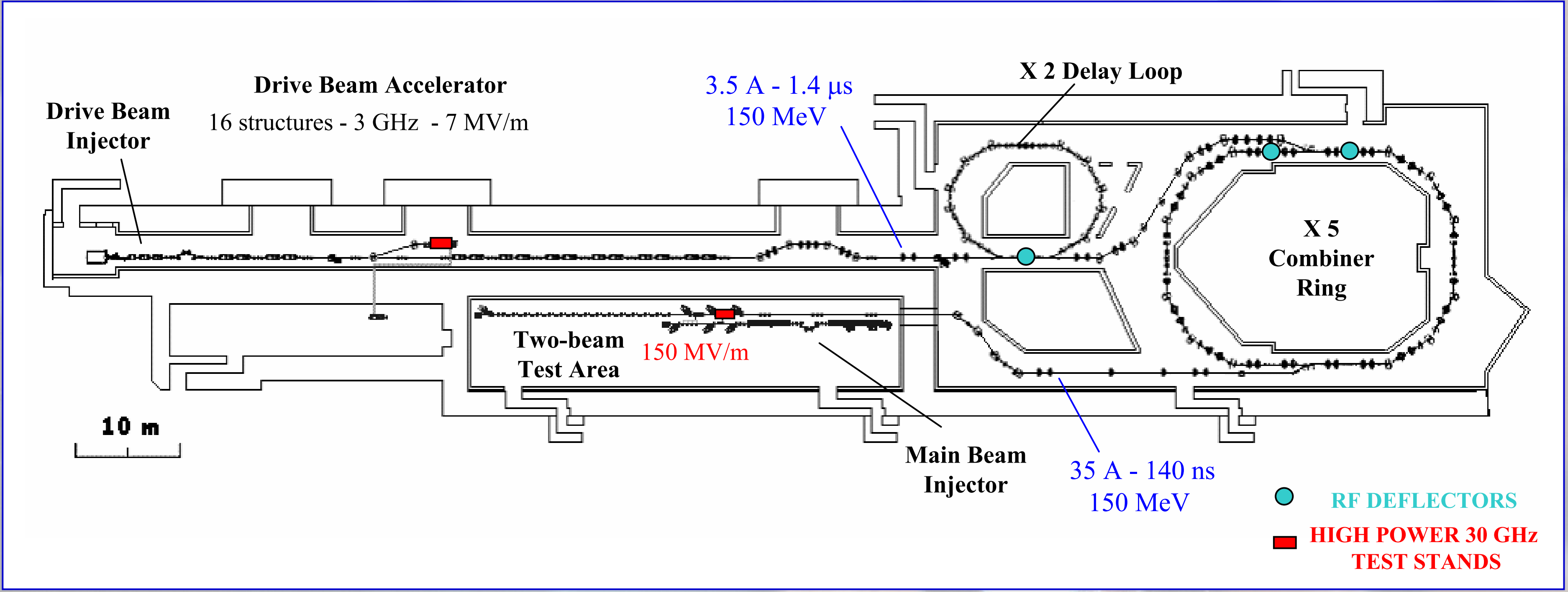


Drive beam time structure - final

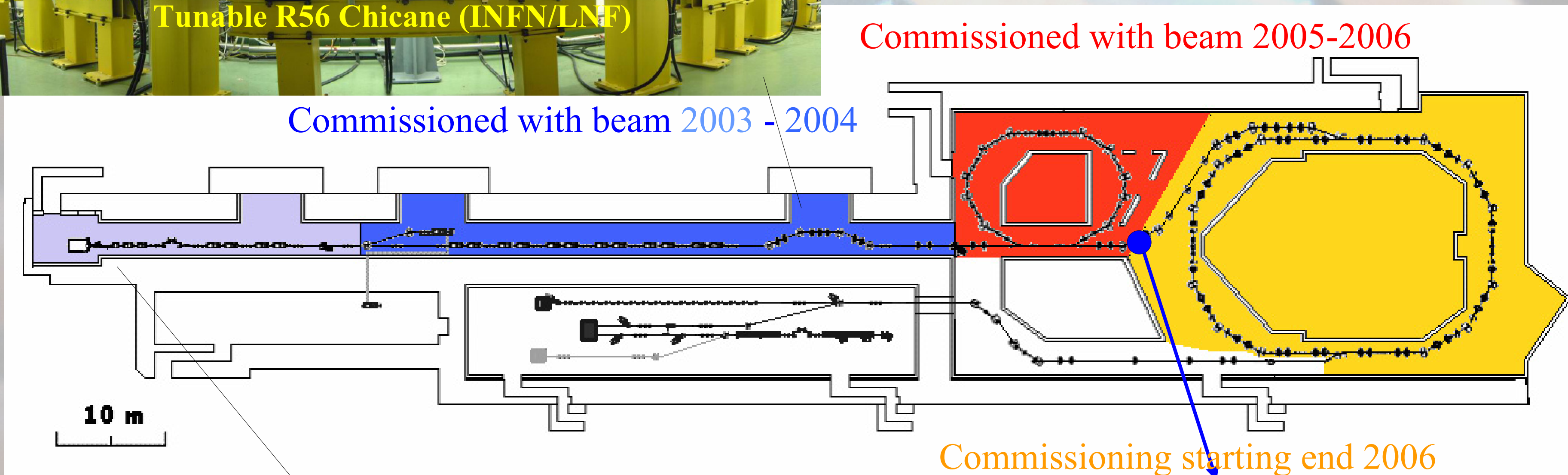


CTF3 motivations and goals

- Build a small-scale version of the CLIC RF power source, in order to demonstrate:
  - full beam loading accelerator operation (power is zero at downstream end of the structure).
  - electron beam pulse compression & 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) .



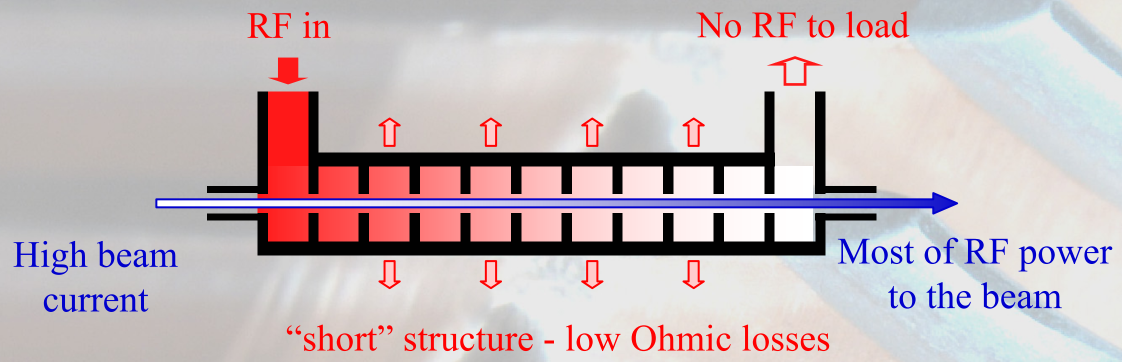
CTF3 Status



Main beam parameters

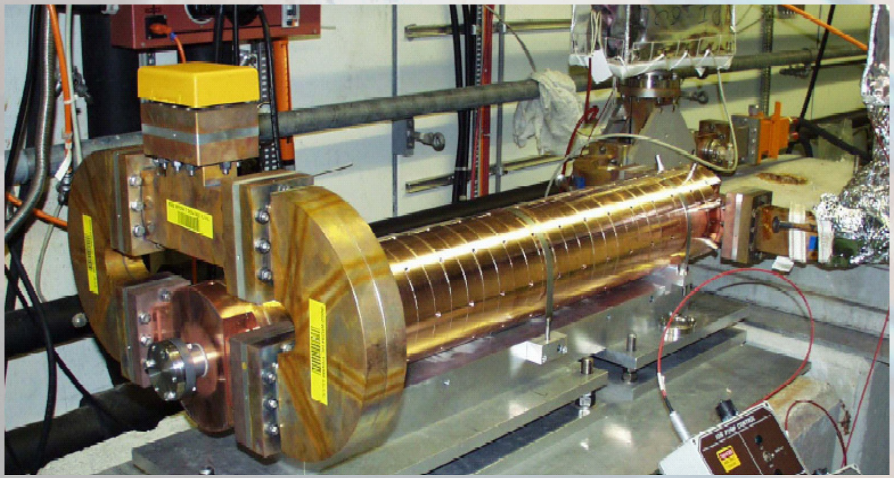
	Nominal	Achieved
I	3.5 A	5 A
τ_p	1.5 μs	1.5 μs
E	150 MeV	100 MeV
$\varepsilon_{n,rms}$	100 π mm mrad	100 π mm mrad
$\tau_{b,rms}$	5 ps	4 ps

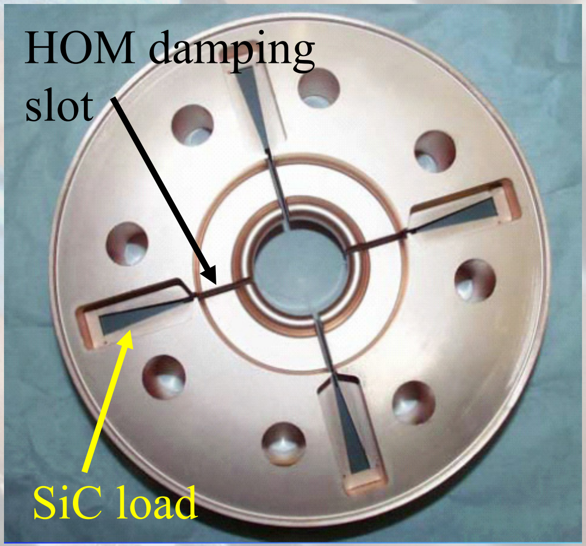
Fully beam loading operation in CTF3



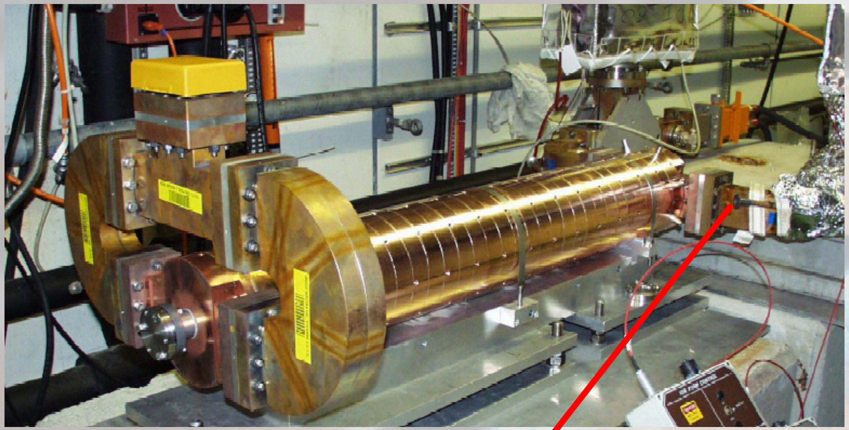
CTF3 Drive Beam Acc. Structures (3 GHz) – SICA (Slotted Iris – Constant Aperture):

- 32 cells
- 1.2 m long
- 2π/3 mode
- 6.5 MV/m av. acc. gradient for 3.5 A beam current
- HOM damping slots

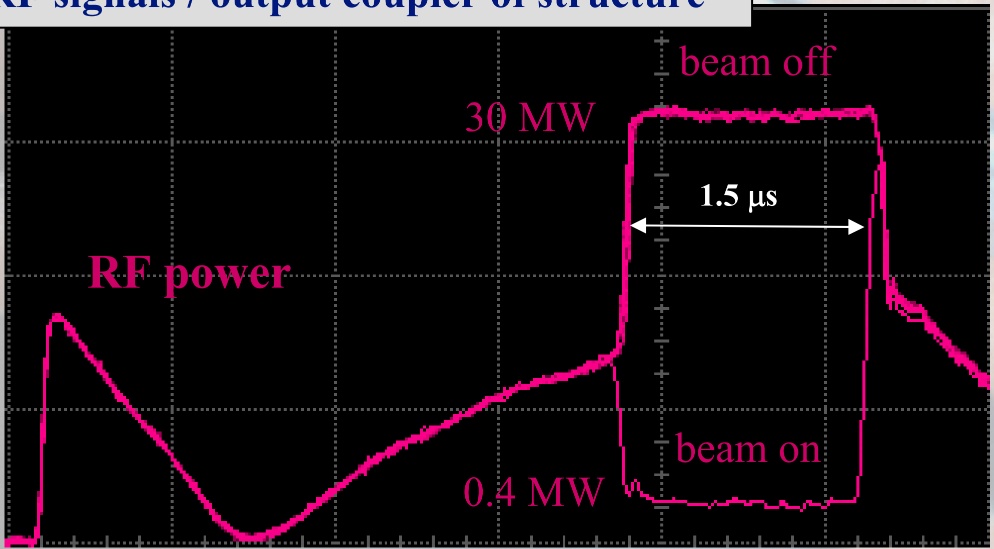




Full beam loading operation in CTF3



RF signals / output coupler of structure



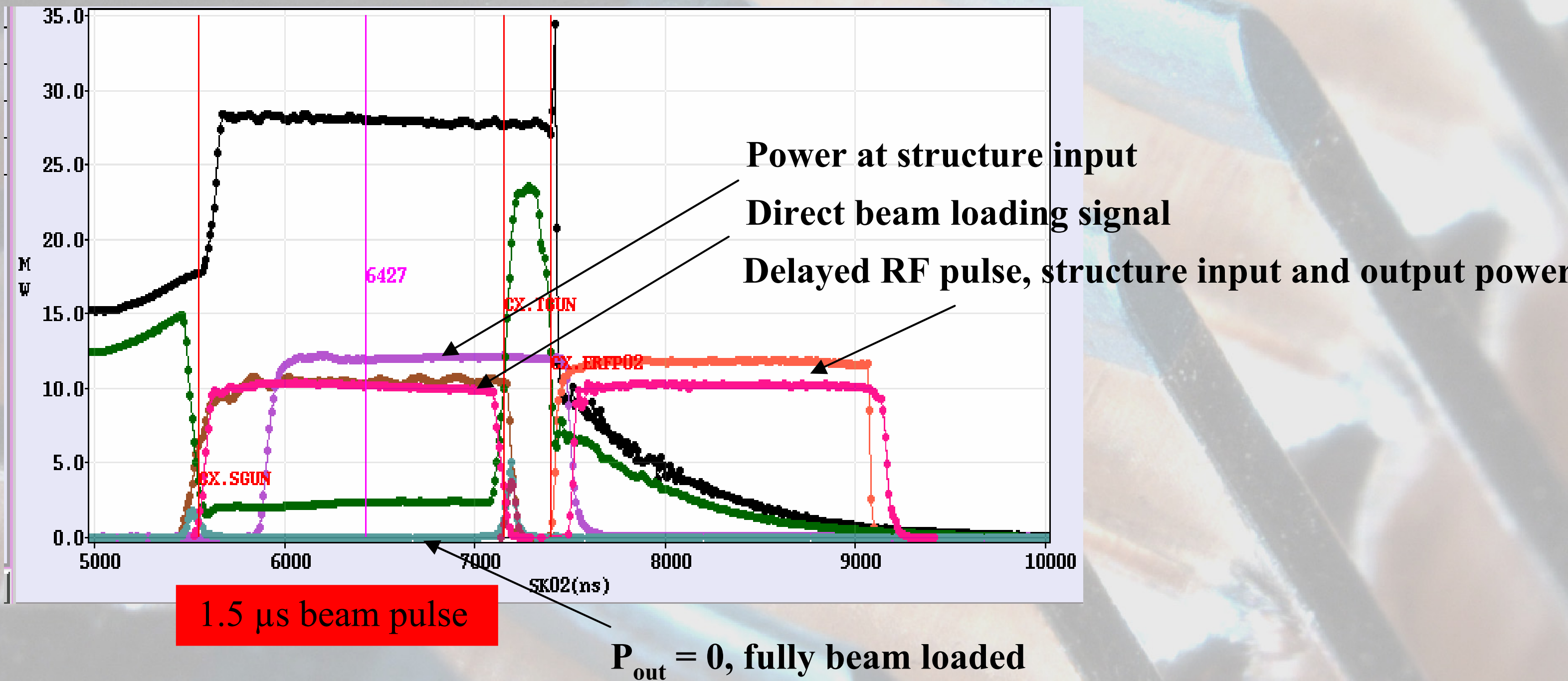
Compressed RF Pulse:

Beam current	4 A
Beam pulse lenght	1.5 μs
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%*

* No beam energy measurements have been performed

Full beam loading operation in CTF3 – Demonstration for CLIC operation

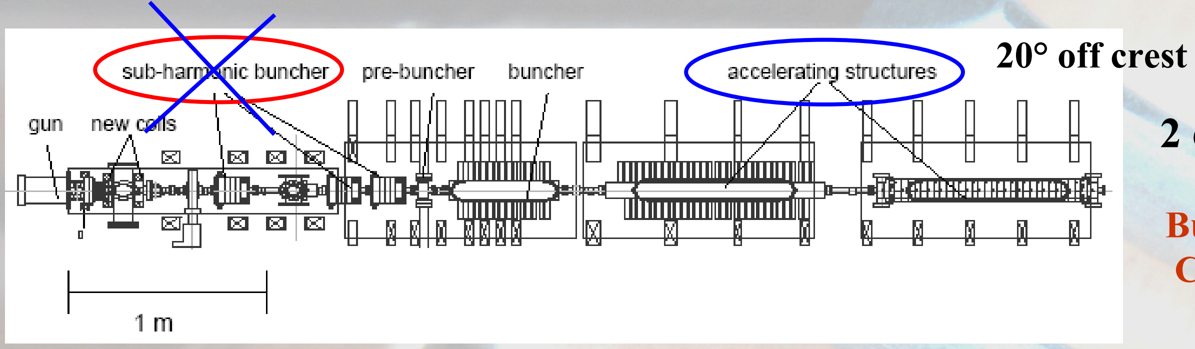
- No RF Pulse compression
- one klystron pulse at a time was delayed after the beam pulse
- measured the difference in energy (“missing” acceleration, deceleration due to direct beam loading)

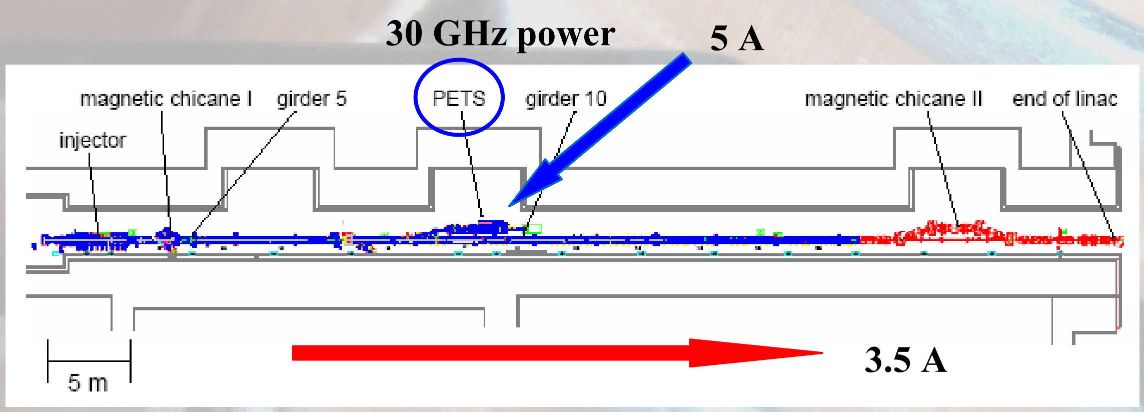


measured RF-to-beam efficiency: 95.3 % (~4 % ohmic losses)

Emittance Optimization of the CTF3 Injector

CTF3 Injector in 2005, new coils (decrease of emittance by a factor 2 (Parmela Simulations))





2 different modes of operation:

Bunch frequency multiplication (DL, Combiner Ring commissioning):

3.5 A beam current
3 sub harmonic buncher (1.5 GHz)
on crest acceleration in all structures

30 GHz Power production mode:

5 A beam current
sub harmonic buncher off
off crest acceleration before magnetic chicane

- Nominal emittance (normalised, rms): 100 π mm mrad (for 3.5 A on crest operation)
- Simulation: 15 - 25 π mm mrad (3.5 A/ 5 A, on/off crest, after magnetic chicane)
- Bunch length: 5 ps, < 2 ps in power mode

Emittance measurements in the CTF3 Linac

3 positions to measure emittance (by means of a quadrupole scan and OTR screen)

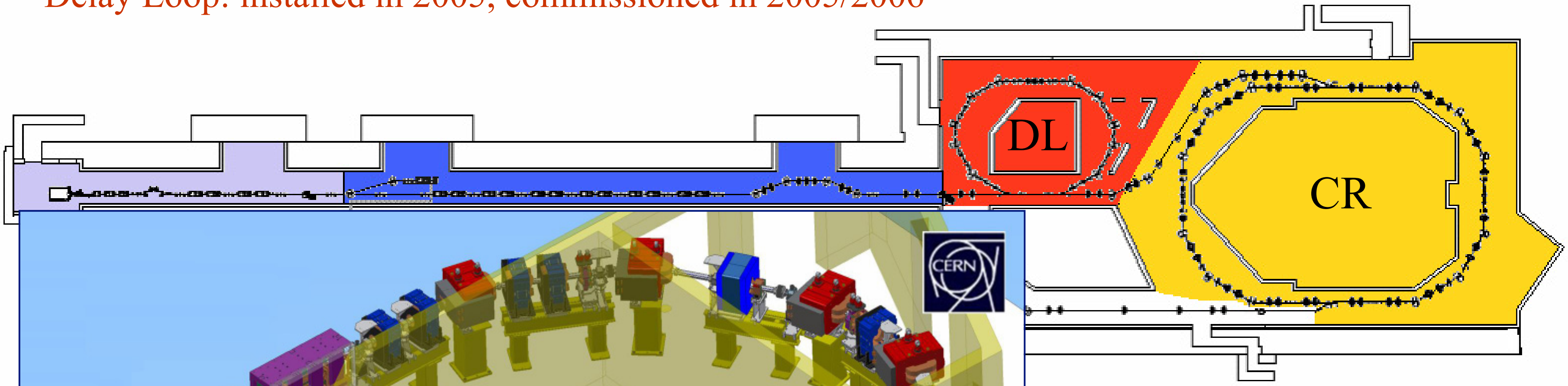
Measurement results:

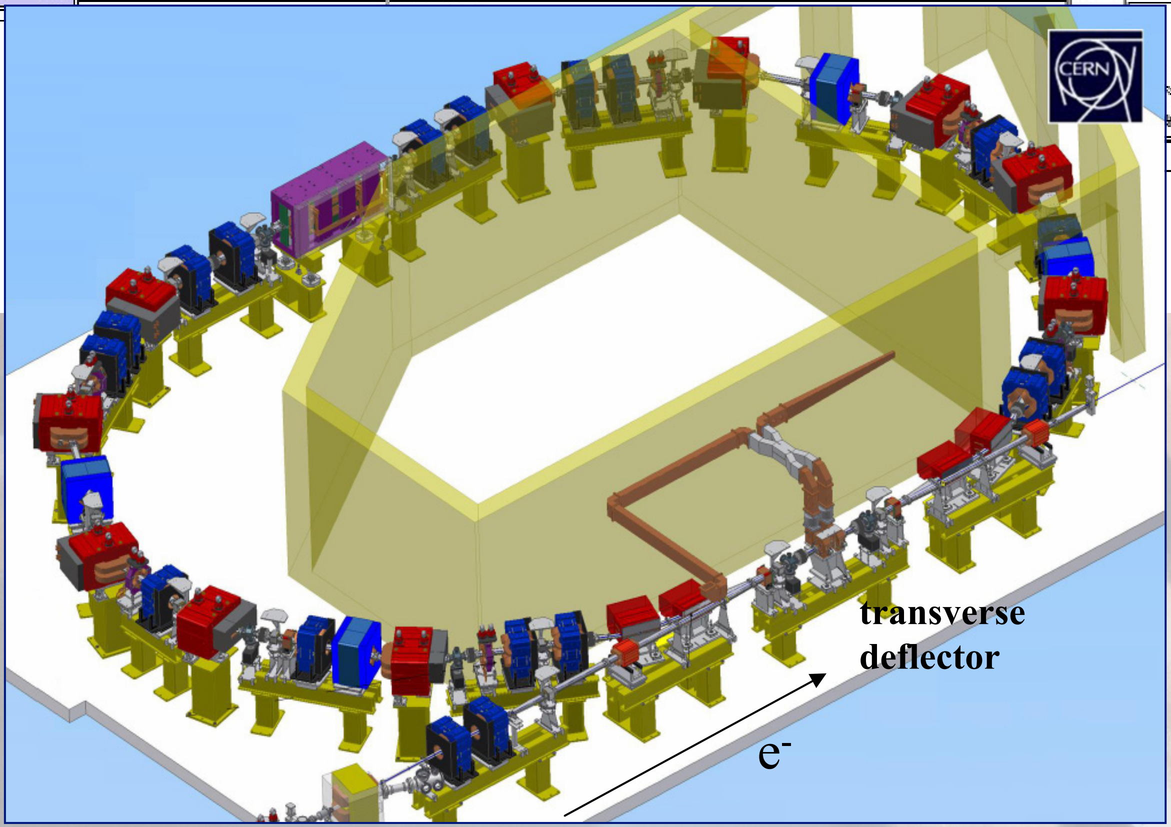
Mode of operation	Bunch frequency	$Emittance_{n,rms}$ (Position 1)	$Emittance_{n,rms}$ (Position 2)	$Emittance_{n,rms}$ (Position 3)
going straight	3 GHz	35 π mm mrad	50 π mm mrad	
going straight	1.5 GHz		60 π mm mrad	80 π mm mrad
30 GHz power	3 GHz	50 π mm mrad	80 π mm mrad	

- At girder 5 we are not to far from simulations
- Measurement results always below the nominal emittance (100 π)
- Power production: good transmission through the PETS (90%)
- Increase of emittance towards the end of the Linac… related to the measurement (resolution, different quadrupole scan range) or beam property? … to be investigated…

Commissioning of the Delay Loop

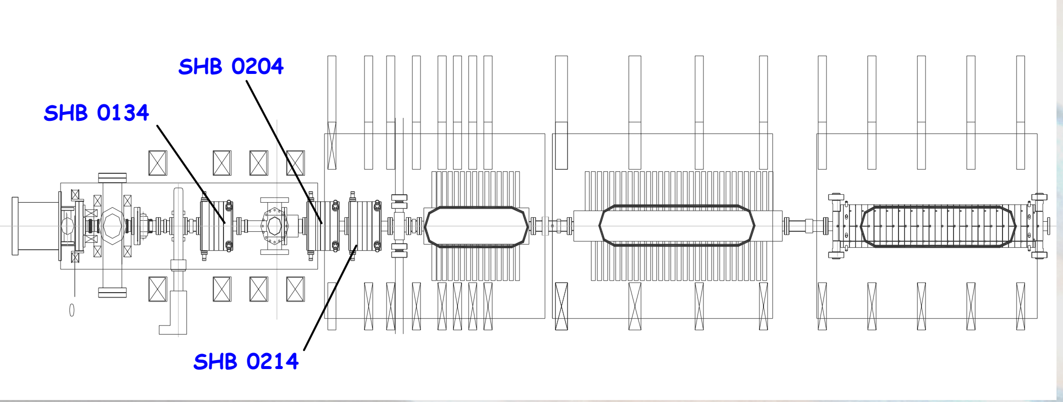
Delay Loop: installed in 2005, commissioned in 2005/2006



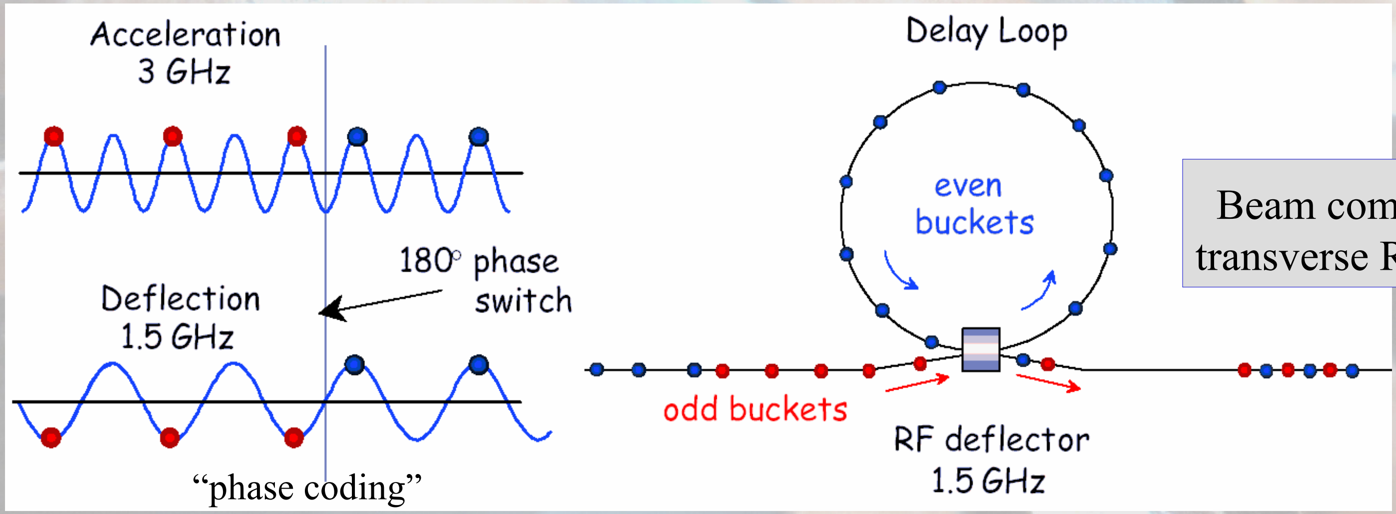


How does the frequency multiplication work?

CTF3 Injector with SHB system



Phase coding and bunch frequency multiplication in delay loop

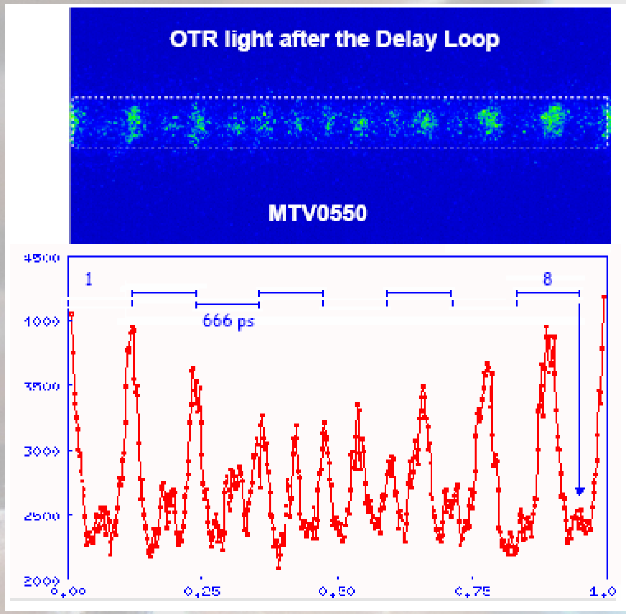


Beam combination with transverse RF deflector

Commissioning of the Delay Loop - SHBs

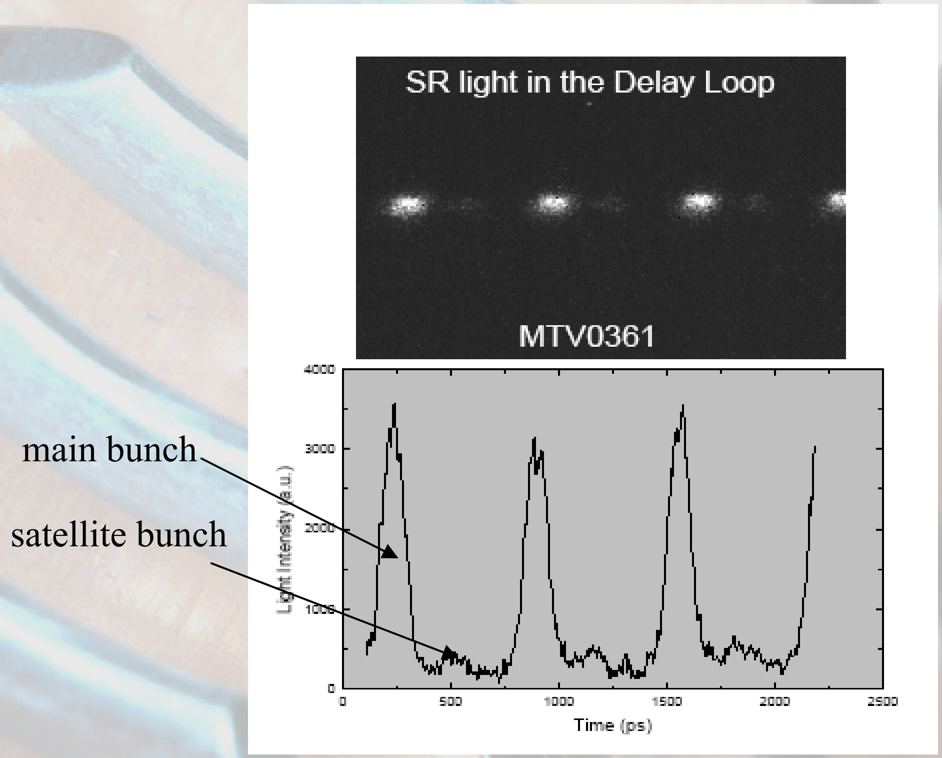
Key parameters for the sub-harmonic bunching system: 1) phase switch time < 10 ns
2) satellite bunch population < 7 %

phase switch:



Phase switch is done within eight 1.5 GHz periods (<6 ns).

satellite bunches:

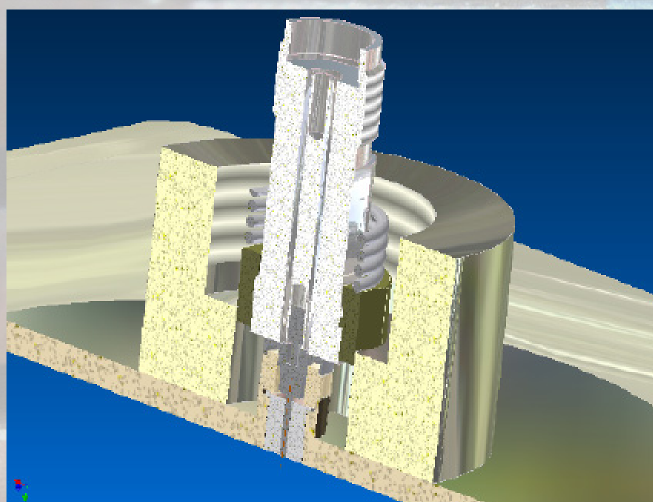


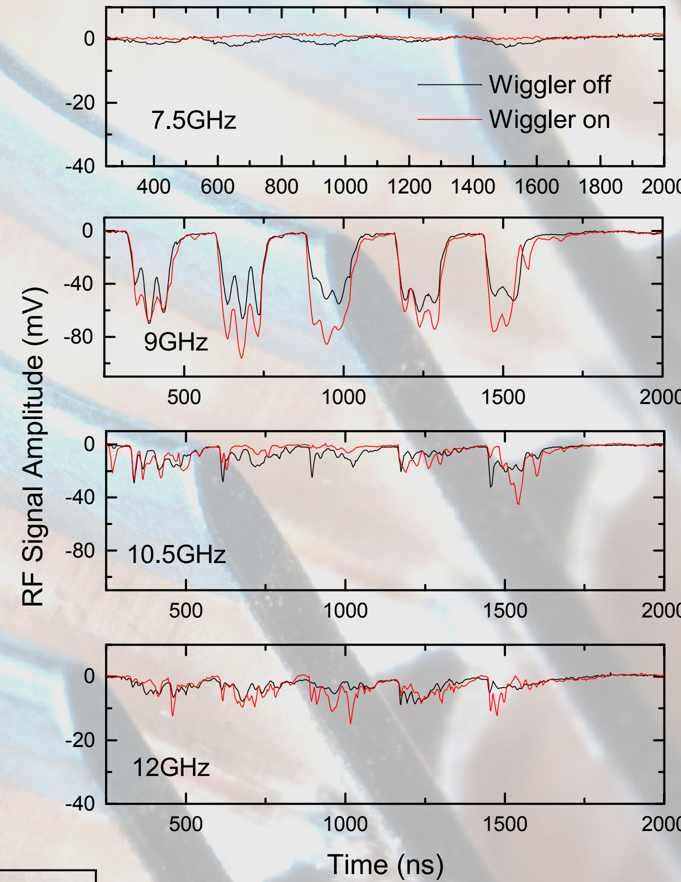
Satellite bunch population was estimated to ~8 %.

Delay Loop, path length tuning

DL wiggler has path length tuning range of ~ 9 mm

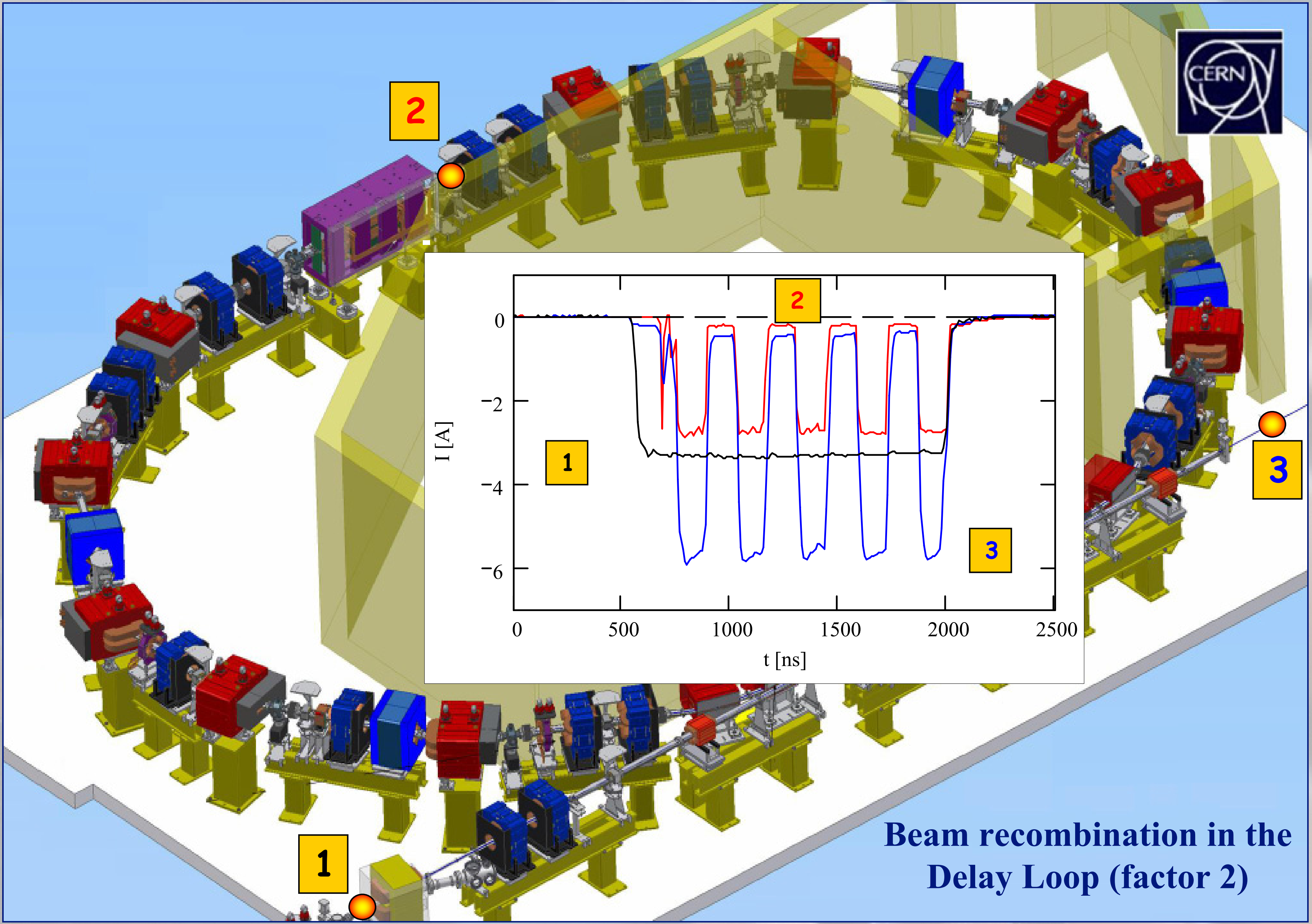
RF phase monitor after the DL to measure phase error in the RF bunch combination.





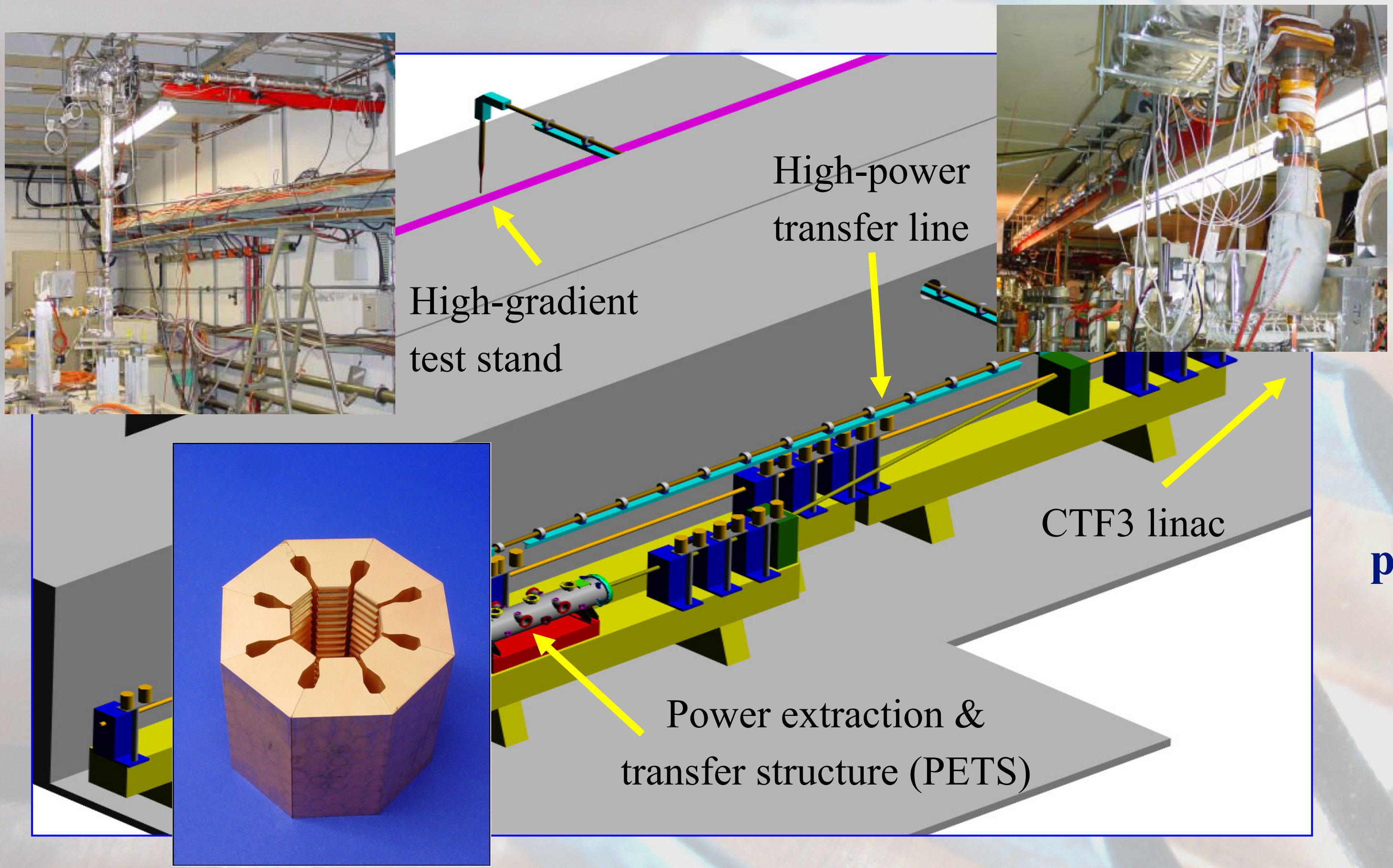
measure harmonics of 1.5 GHz.

Better RF combination
- 7.5 & 10.5GHz ↘
- 9 & 12 GHz ↗



Beam recombination in the Delay Loop (factor 2)

30 GHz power production in CTF3

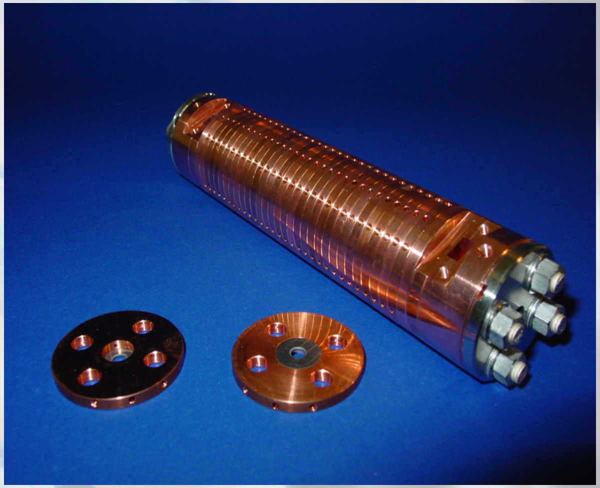


- Produced power up to about 100 MW - structure tests started in 2005
- 5 structures tested until now

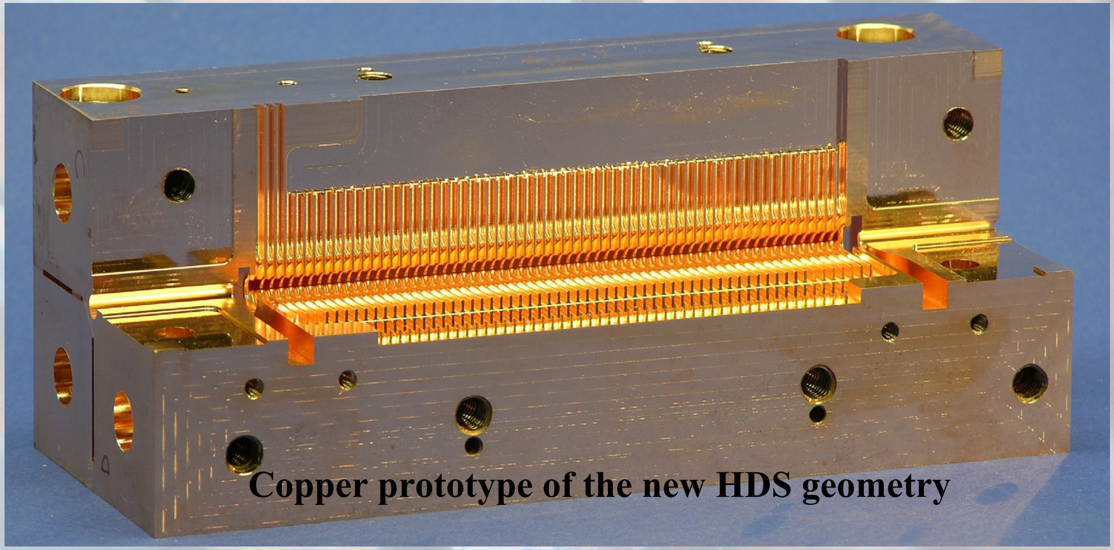
Acceleration structures

Structures tested so far (or under test) in CTF3:

Structure	Assembly	N. of cells	test. time [h]
Circular Cu	Brazed cells	30	400
Circular Mo	Clamped cells	30	230
HDS 60 - Cu	Clamped quad	60	375
HDS 60 – Cu (rev)	Clamped quad	60	400
HDS 11 - Mo	Clamped quad	11	~300
HDS 11 - Ti	Clamped quad	11	just started

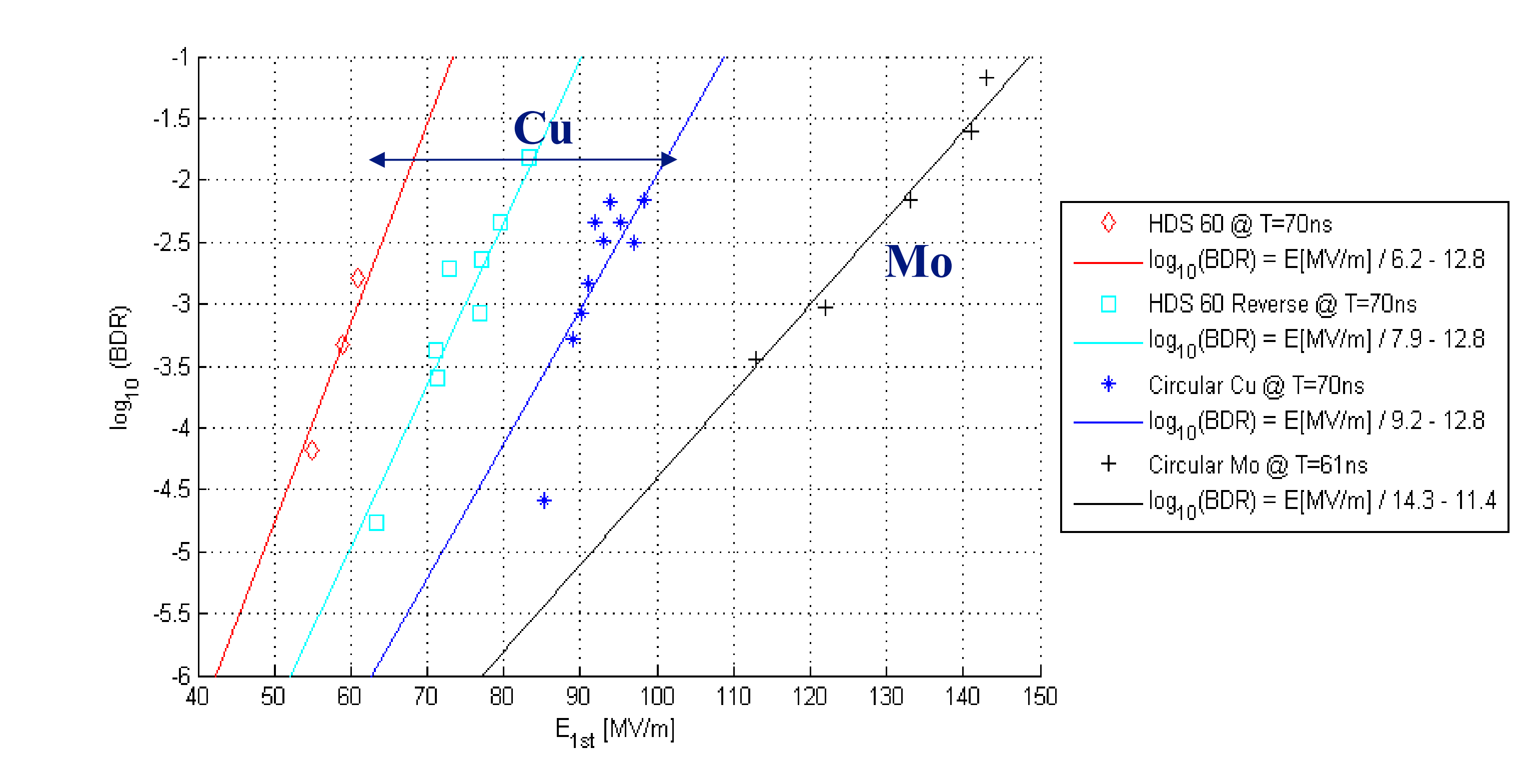


Phase advance/cell in degree	60
Cell length [mm]	1.666
Iris radius (first, last) [mm]	2.06, 1.50
Iris thickness (first, last) [mm]	0.27, 0.37
Q-factor (first, last)	2590, 2244
N_{cell}	140
Active structure length [mm]	233
P_{in} [MW]	151



Copper prototype of the new HDS geometry

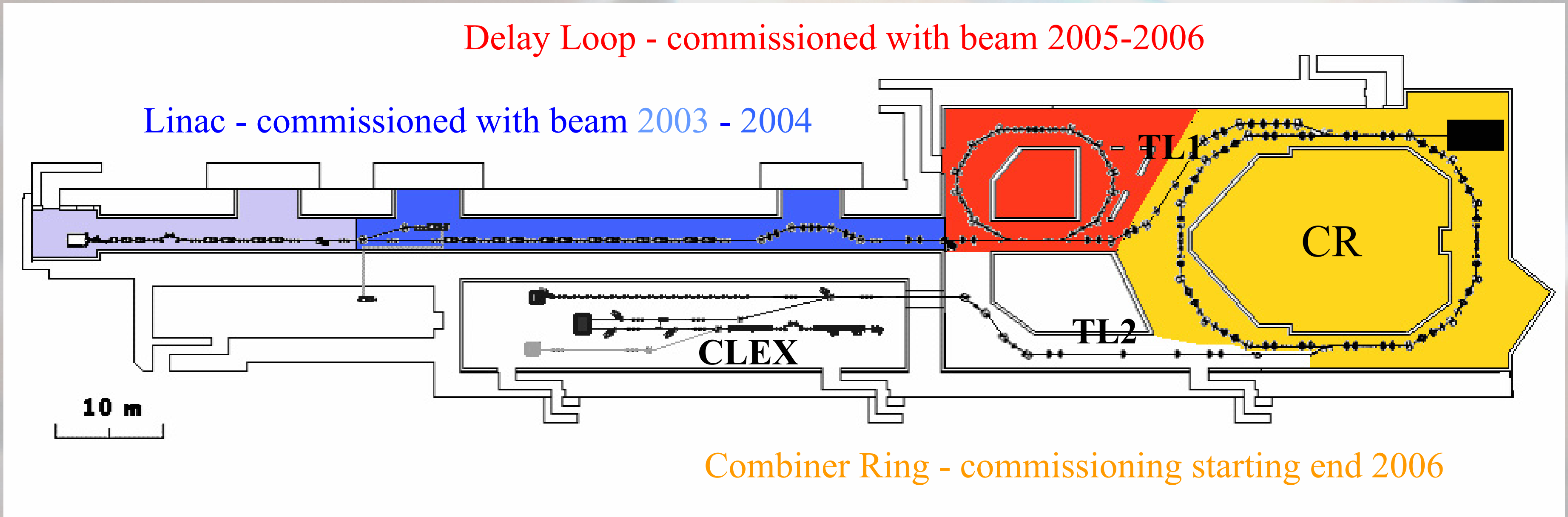
CTF3 High-Power test results – Break Down Rate Experiments



Results & open questions:

- HDS geometry tested (Cu) – no major problem – small decrease of performance (under investigation)
- Mo HDS tests just finished – slope as steep as for copper!
- Breakdown rate slope for Mo less steep than Cu – material or clamping dependent ?
- Titanium HDS under test right now (first results look promising)

Future CTF3 Activities



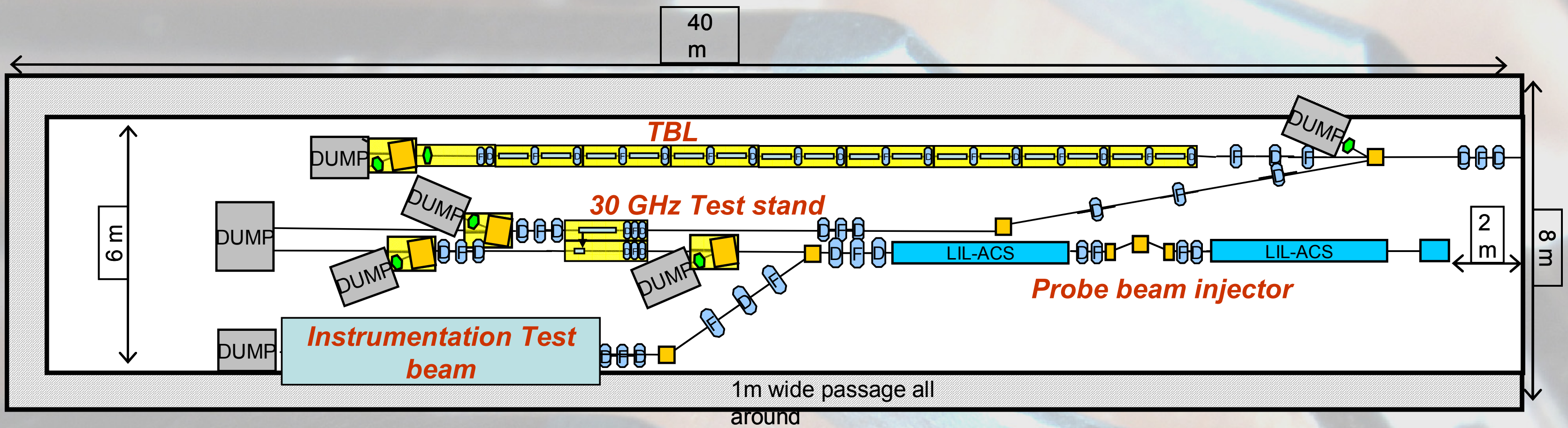
Commissioning Steps:

Transfer Line 1 and CR Injection at the end of 2006

Combiner Ring and Transfer Line 2 in 2007

CLEX (CTF3 Experimental Area) from 2008 on

Future CTF3 Activities - CLEX



3 activities:

- **30 GHz Test Stand:**

  1) Demonstration of the operation of a full CLIC module. 35 A drive beam with 140 ns pulse length, PETS to produce up to 300 MW power, acceleration of the probe beam.

  2) Measure effects of RF breakdown on the drive beam, crucial for acceptable breakdown rate.

- **Test Beam Line:**

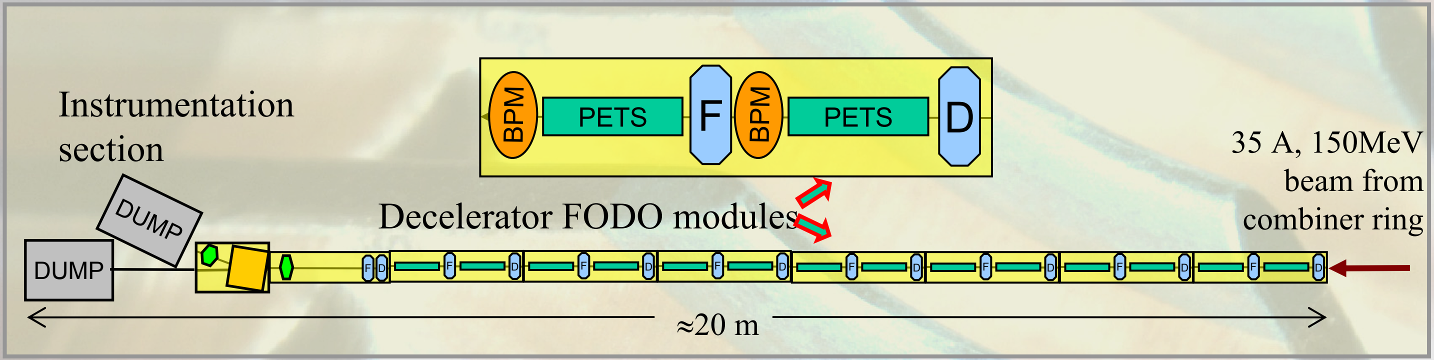
  Validation of the Drive beam stability.

- **Instrumentation Test beam:**

  Use of the probe beam for various instrumentation tests.

Future CTF3 Activities - CLEX

Test Beam Line:



Main concerns for CLIC drive beam decelerators

- Beam of very high current (180 A) and damage potential
- Total energy spread of up to 90%. Beam is decelerated to 10% of its initial energy
- Wakefield effects

TBL as a scaled model of a CLIC drive beam decelerator allows to test the operation and instrumentation for such a decelerator and to benchmark the simulation tools.

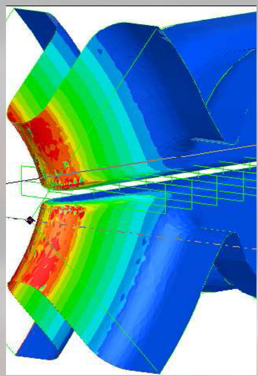
CONCLUSIONS

- **CLIC is the only possible scheme to extend the Linear Collider energy into the Multi-TeV range**
- **CLIC technology is not mature yet, requires a lot of challenging R&D**
- **Very promising results were already obtained in CTF II and in the first stages of CTF3**
    - e.g. recently the Delay Loop commissioning

Aim to provide the High Energy Physics community with the feasibility of CLIC technology in due time, when physics needs will be fully determined following LHC results (2010?).

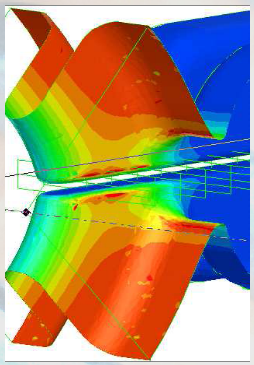
Safety net to the SC technology in case sub-TeV energy range is not considered attractive enough for physics.

Acceleration structure fabrication



E-field (breakdown)

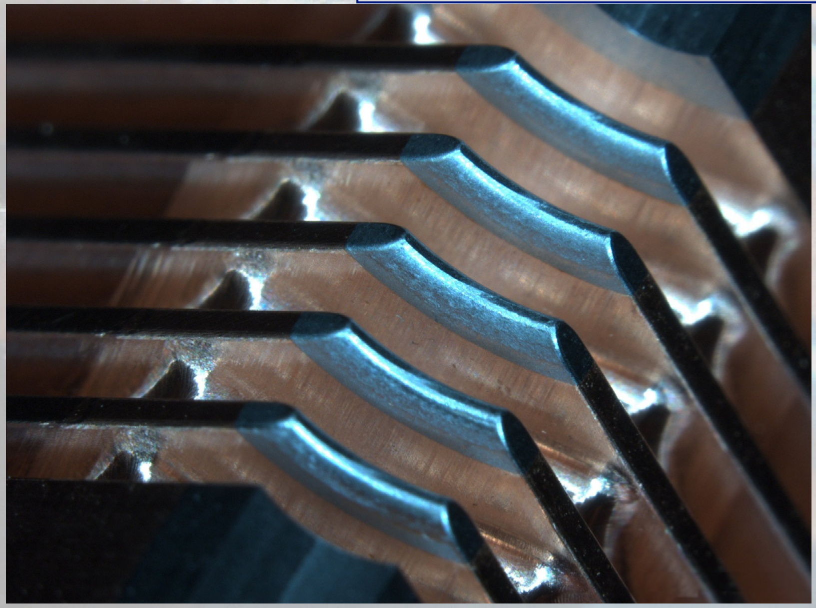
⇨use of **Mo**, or alternative refractory metal.

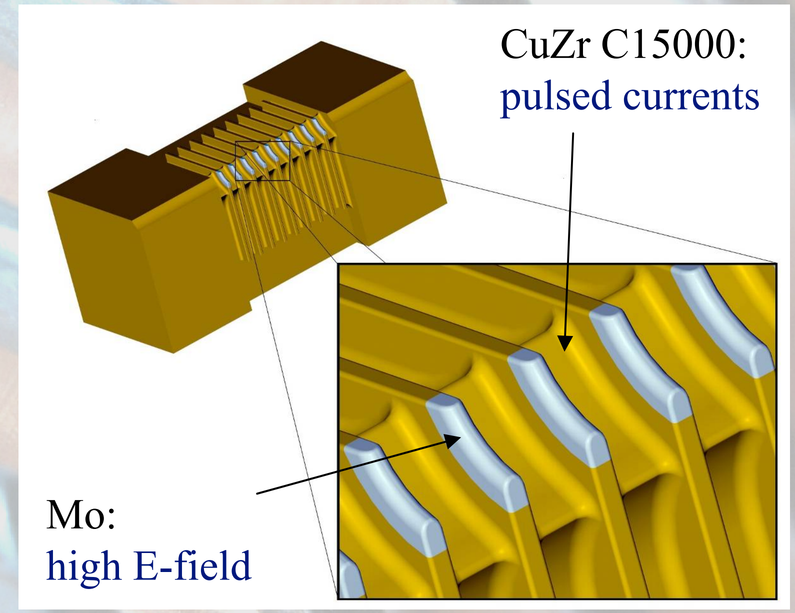


Pulsed currents (fatigue)

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

⇨Use bi-metallic

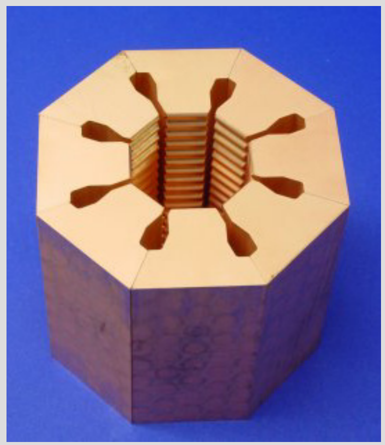


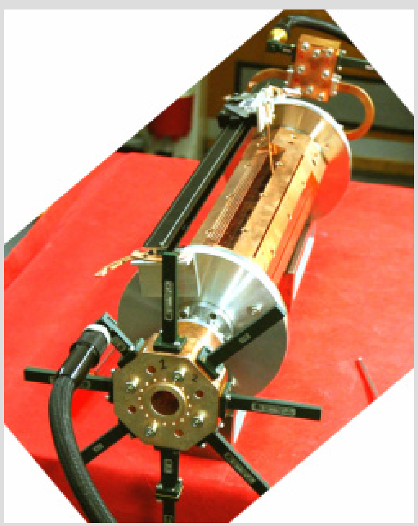


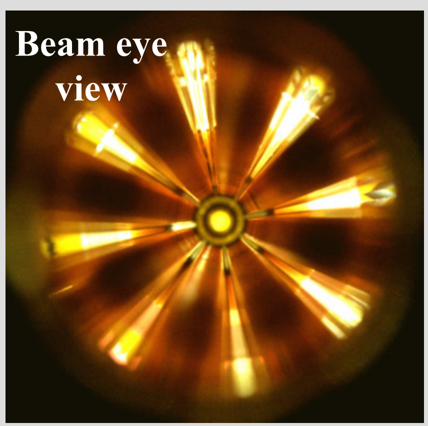
Power Extraction & Transfer Structure

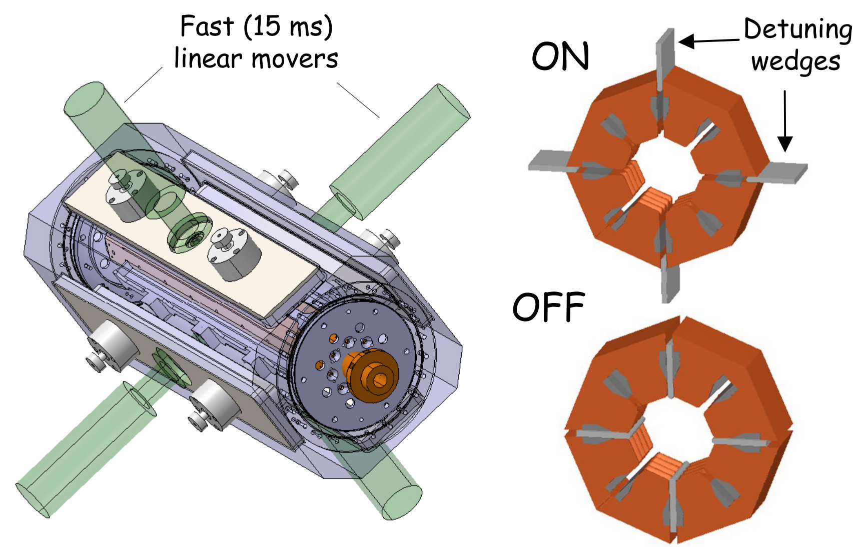
- In interaction with the drive beam, the PETS must produce and efficiently extract a few hundreds MW of RF power.

- The PETS is a periodically corrugated structure with low impedance (big a/λ).









PETS ON/OFF mechanism