
Particle Accelerator Conference 2007
Albuquerque, New Mexico, June 25–29

Talk outline

- Introduction to CLIC & CTF3
  - Parameter change
- CLIC R&D at CTF3
  - Achievements
  - Status & outlook
- Conclusions

Aim of the CLIC study:

develop technology for e-/e+ linear collider with the requirements:

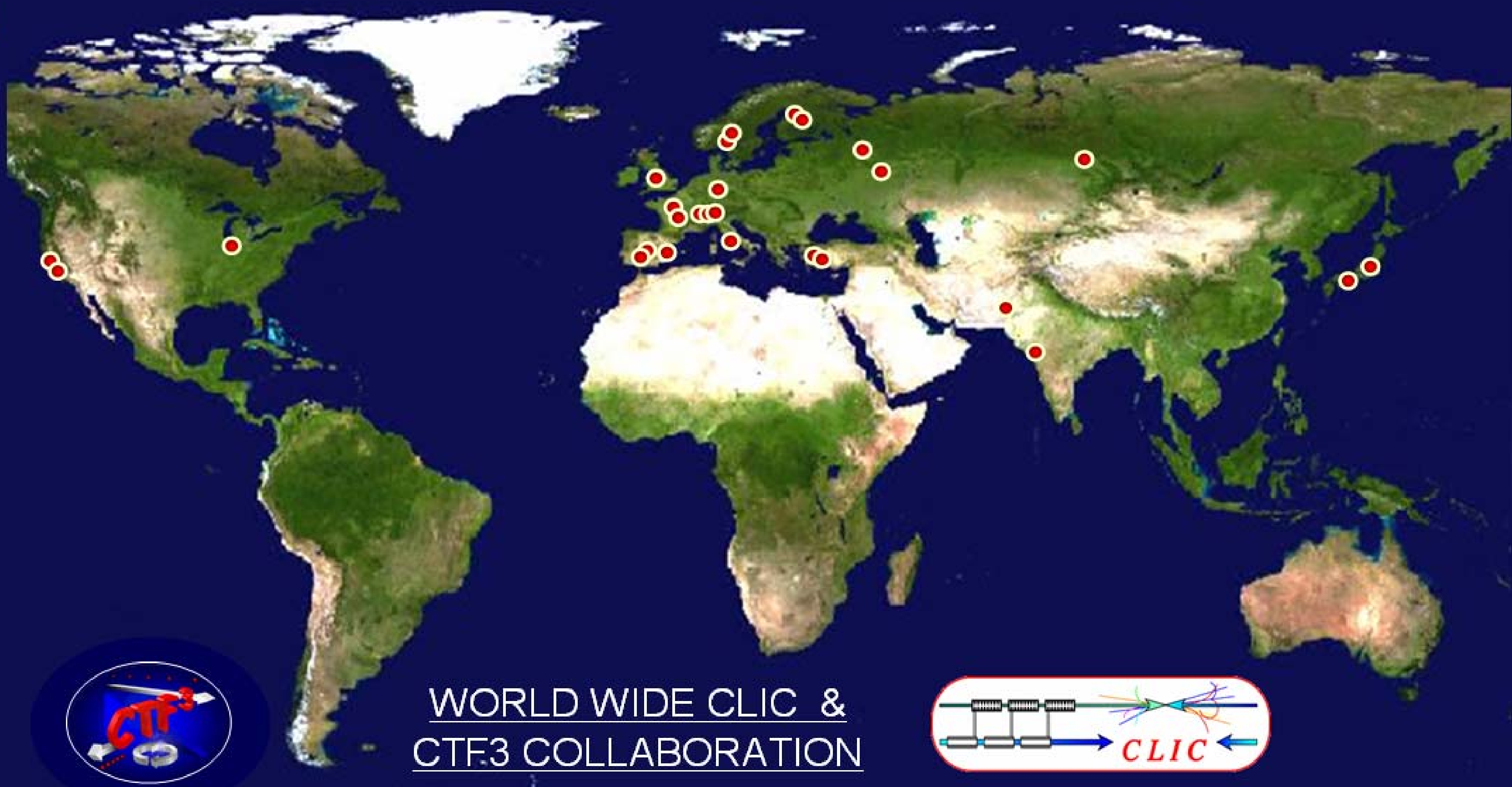
- ✓ E_{CM} should cover range from ILC to LHC maximum reach and beyond ⇒ **E_{CM} = 0.5-3 TeV**, (some physicists keep saying that 5 TeV would be better)
- ✓ L > few **10^{34} cm^{-2}** with acceptable background and energy spread
  - ✓ E_{CM} and L to be reviewed once LHC physics results are available
- ✓ Design compatible with maximum length ~ **50 km**
- ✓ Affordable
- ✓ Total power consumption < **500 MW**

Physics motivation:

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

Present goal:

Demonstrate all key feasibility issues and document in a CDR by 2010 (possibly TDR by 2015)



Ankara University (Turkey)
Berlin Tech. Univ. (Germany)
BINP (Russia)
CERN
CIEMAT (Spain)
DAPNIA/Saclay (France)

RRCAT-Indore (India)
Finnish Industry (Finland)
Gazi Universities (Turkey)
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)
NCP (Pakistan)

PSI (Switzerland),
North-West. Univ. Illinois (USA)
Polytech. University of Catalonia (Spain)
RAL (England)
SLAC (USA)
Svedberg Laboratory (Sweden)
Uppsala University (Sweden)

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

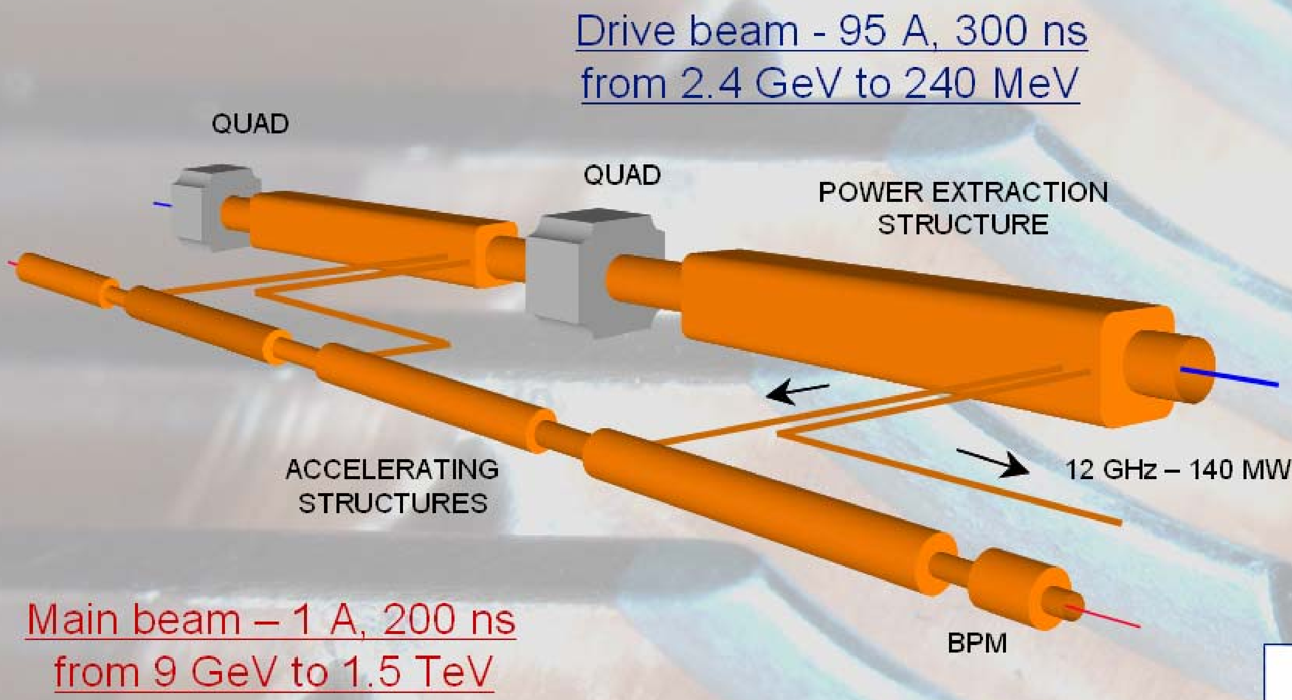
- High acceleration gradient

  - ✓ "Compact" collider - overall length < 50 km
  - ✓ Normal conducting accelerating structures
  - ✓ High acceleration frequency

- Two-Beam Acceleration Scheme

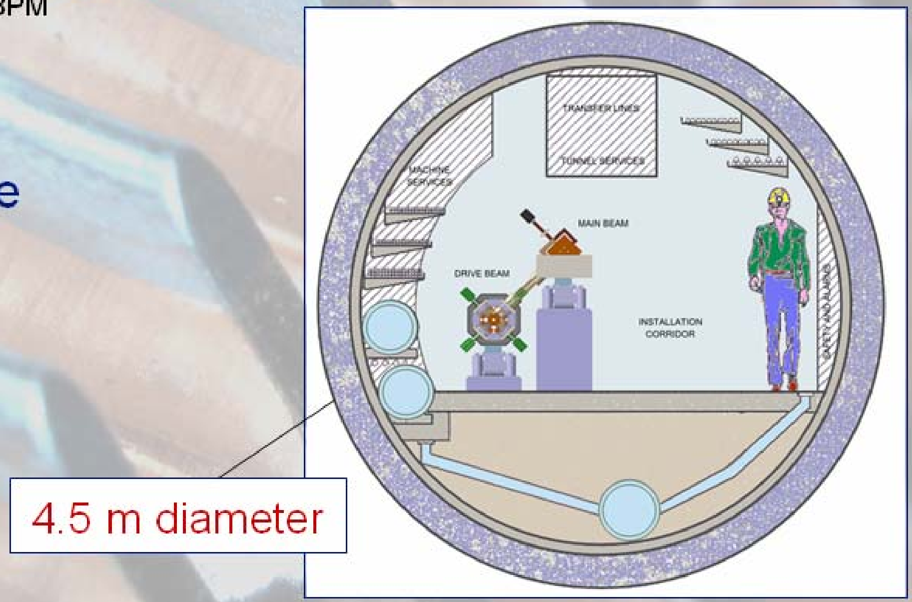
  - ✓ Cost effective, reliable, efficient
  - ✓ Simple tunnel, no active elements
  - ✓ Modular, easy energy upgrade in stages

Results from CLIC proof of principle in CTF3



CLIC Two-Beam scheme

CLIC TUNNEL CROSS-SECTION



Recent changes of key CLIC parameters

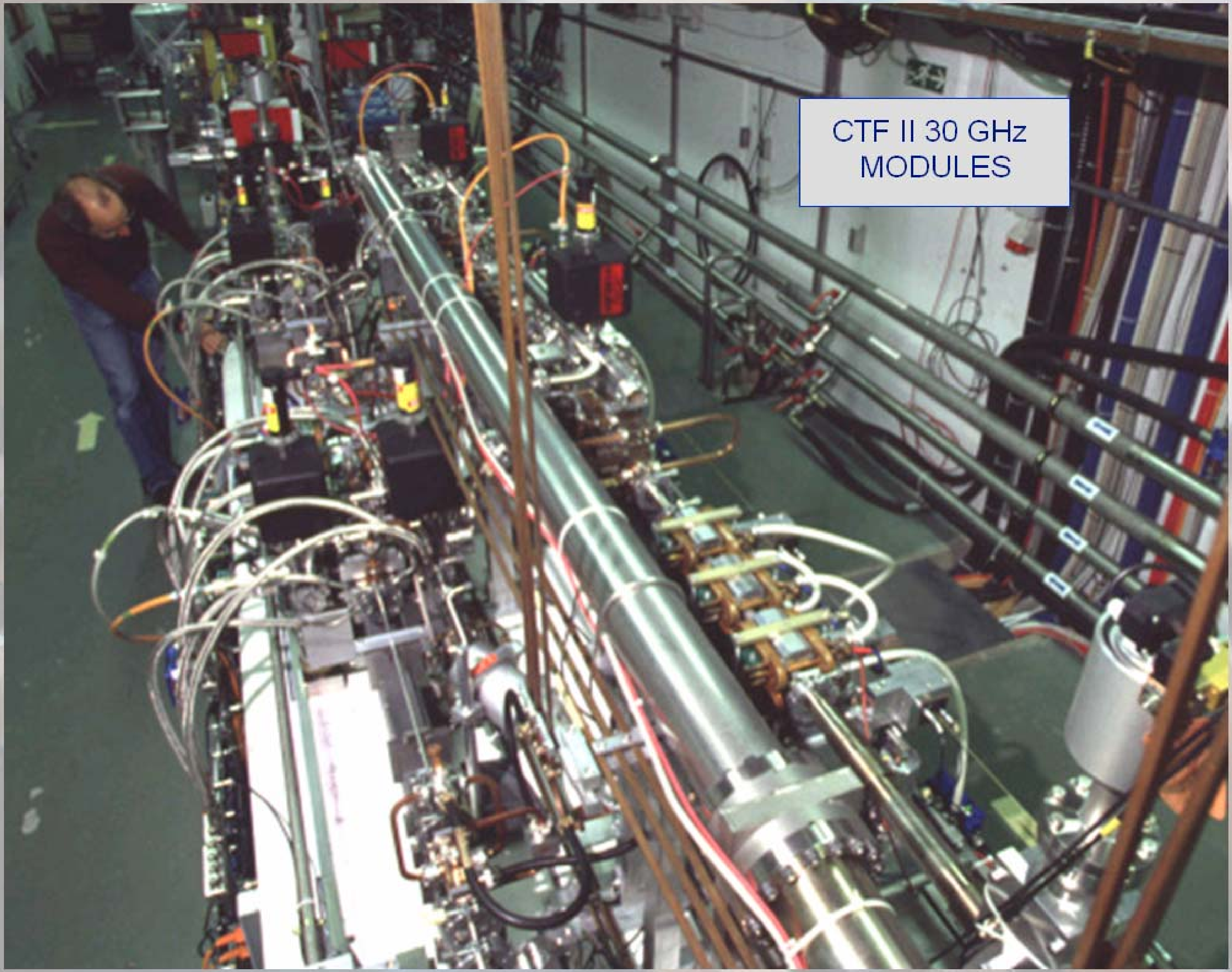
Main Linac RF frequency	**30 GHz**	⇒	**12 GHz**
Accelerating field	**150 MV/m**	⇒	**100 MV/m**
Overall length @ E_{CM} = 3 TeV	**34 km**	⇒	**48 km**

Why?

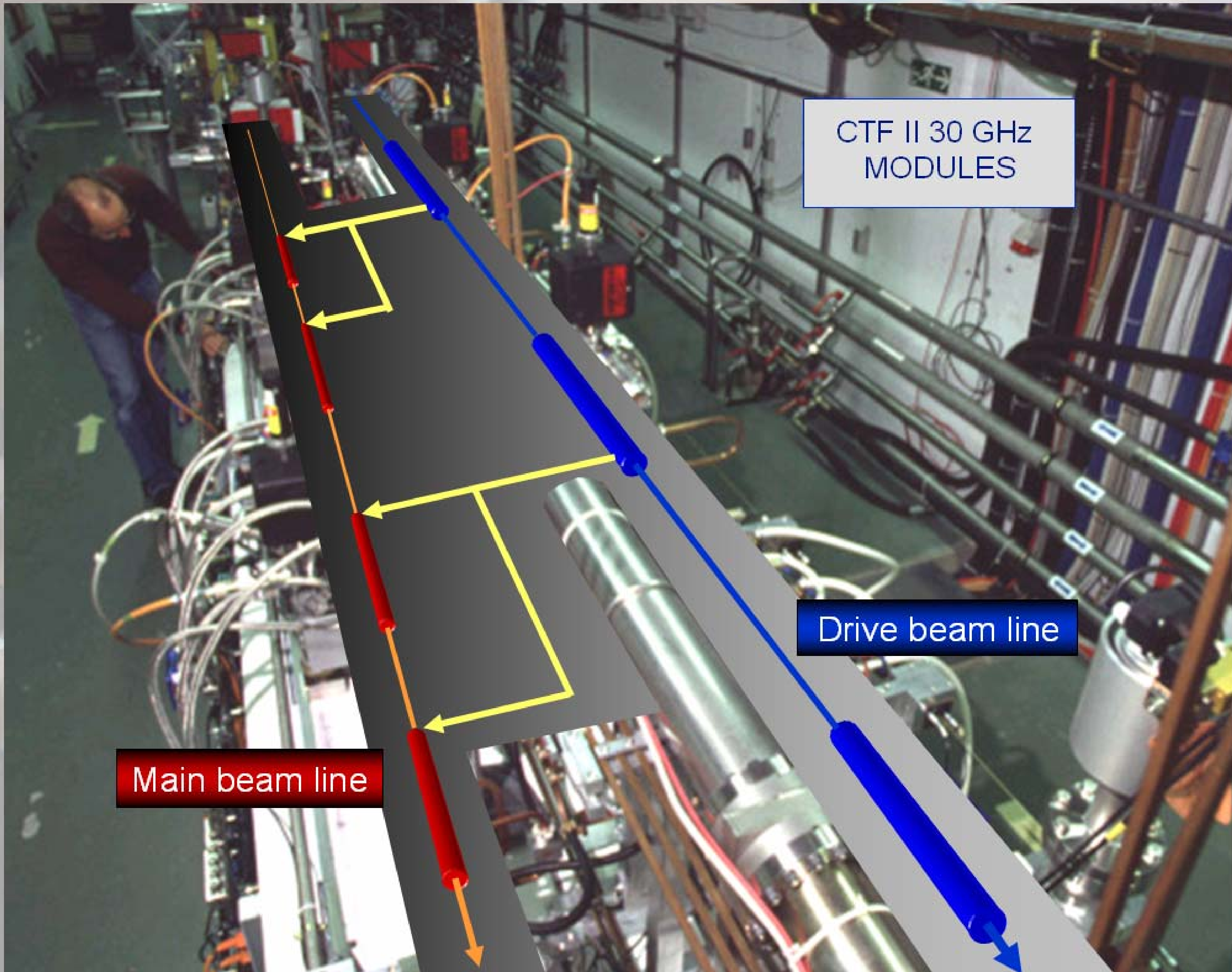
- ✓ Very promising results of earlier Molybdenum test structures not reproduced for test conditions closer to LC requirements (i.e., low breakdown rate, long RF pulses, structures with HOM damping)
- ✓ Copper structure tests indicate flat gradient scaling with frequency above >12 GHz
- ✓ Parametric study indicates higher efficiency and substantial cost savings for 12 GHz / 100 MV/m (flat minimum for this parameter range)
- ✓ 100 MV/m is lowest gradient for a 3 TeV machine

⇒ Concentrate efforts on lower frequency & gradient and copper structures increases chance of feasibility demonstration by 2010

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

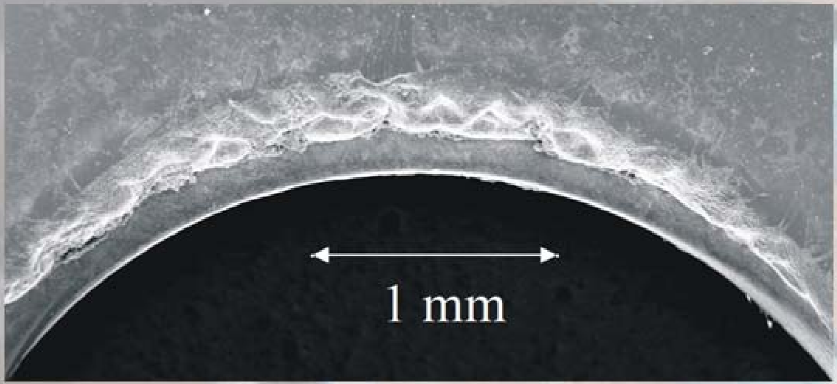


CTF II - Dismantled in 2002, after having achieved its goals

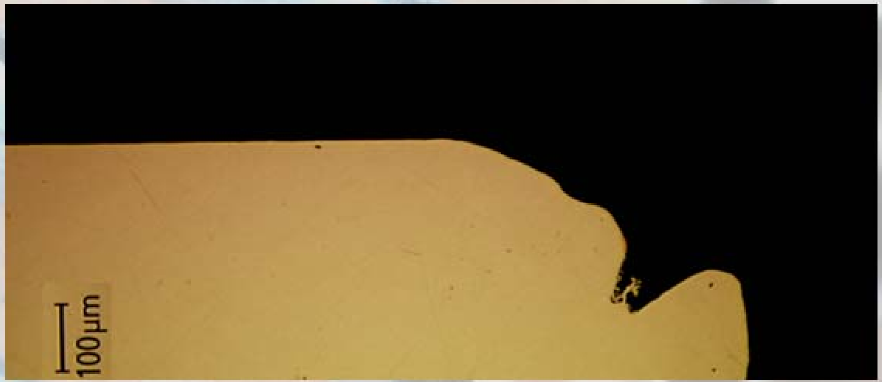


Breakdown and damage of structures

High-power tests of copper accelerating structures in CTF II and NLCTA showed **severe surface damage** from breakdowns for surface fields around **300 - 400 MV/m**.



Microscopic image of damaged iris

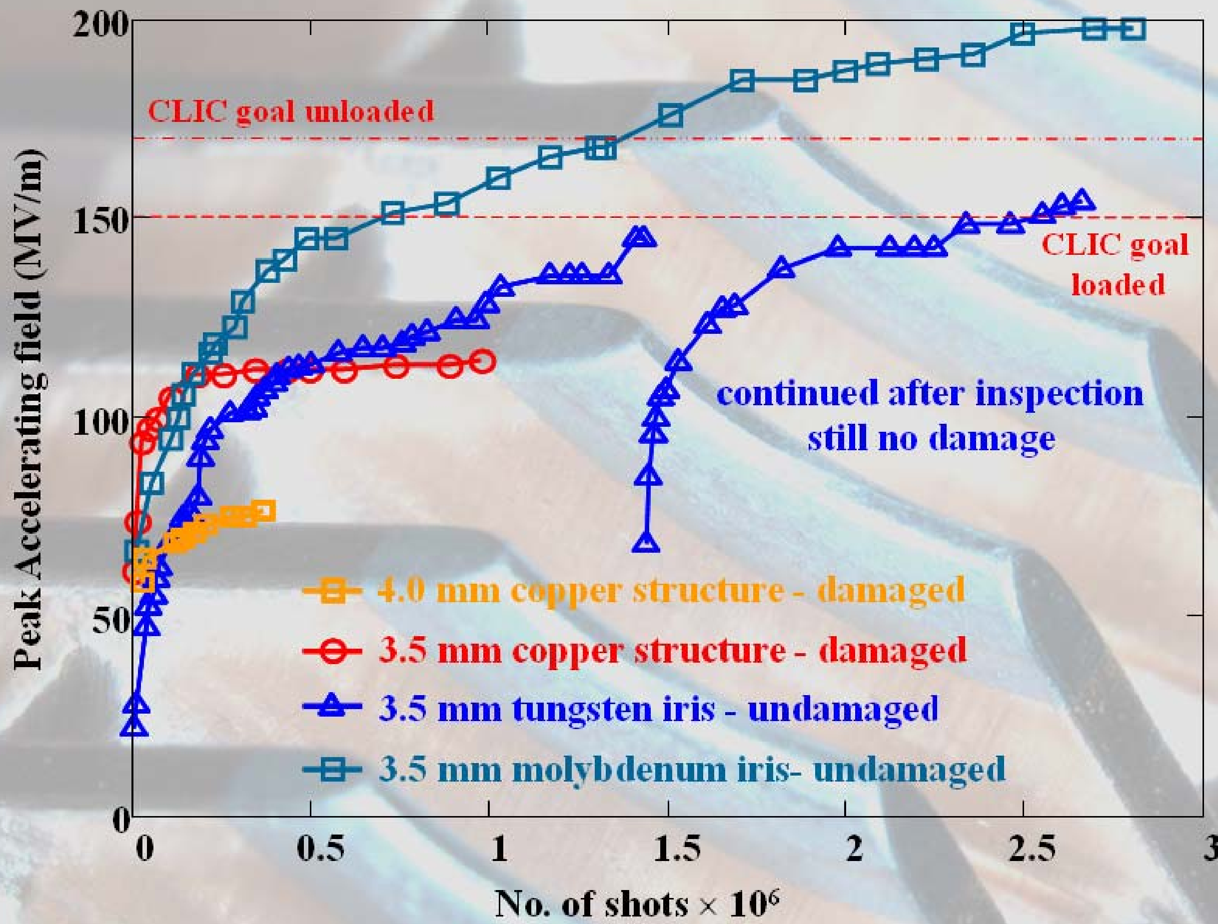


Damaged iris – longitudinal cut

Possible solutions:

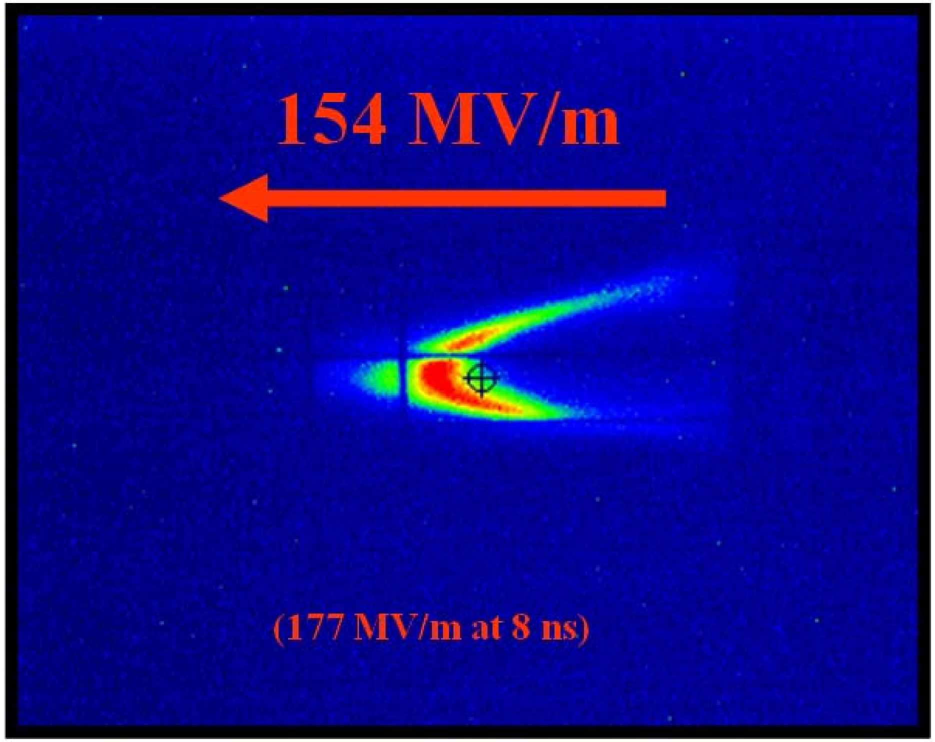
- Optimize the **RF design** to obtain lower surface field to accelerating field ratio **(small a/λ)**
- Investigating **new materials** that are resistant to arcing – (**tungsten, molybdenum…**)

High-gradient tests in CTF II



A 30-cell structure with Mo irises exceeded the CLIC accelerating field requirements without damage

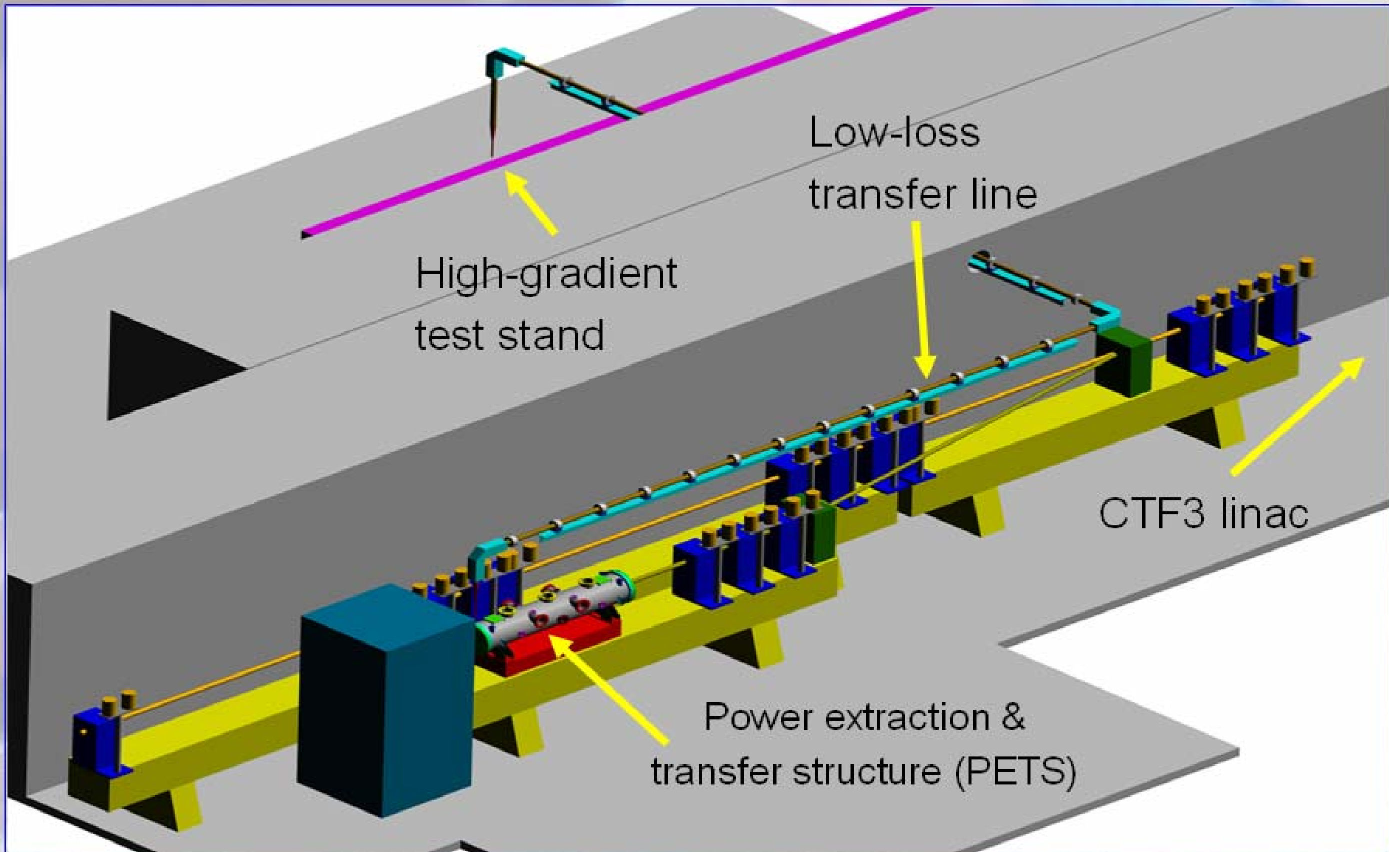
High-gradient tests in CTF II



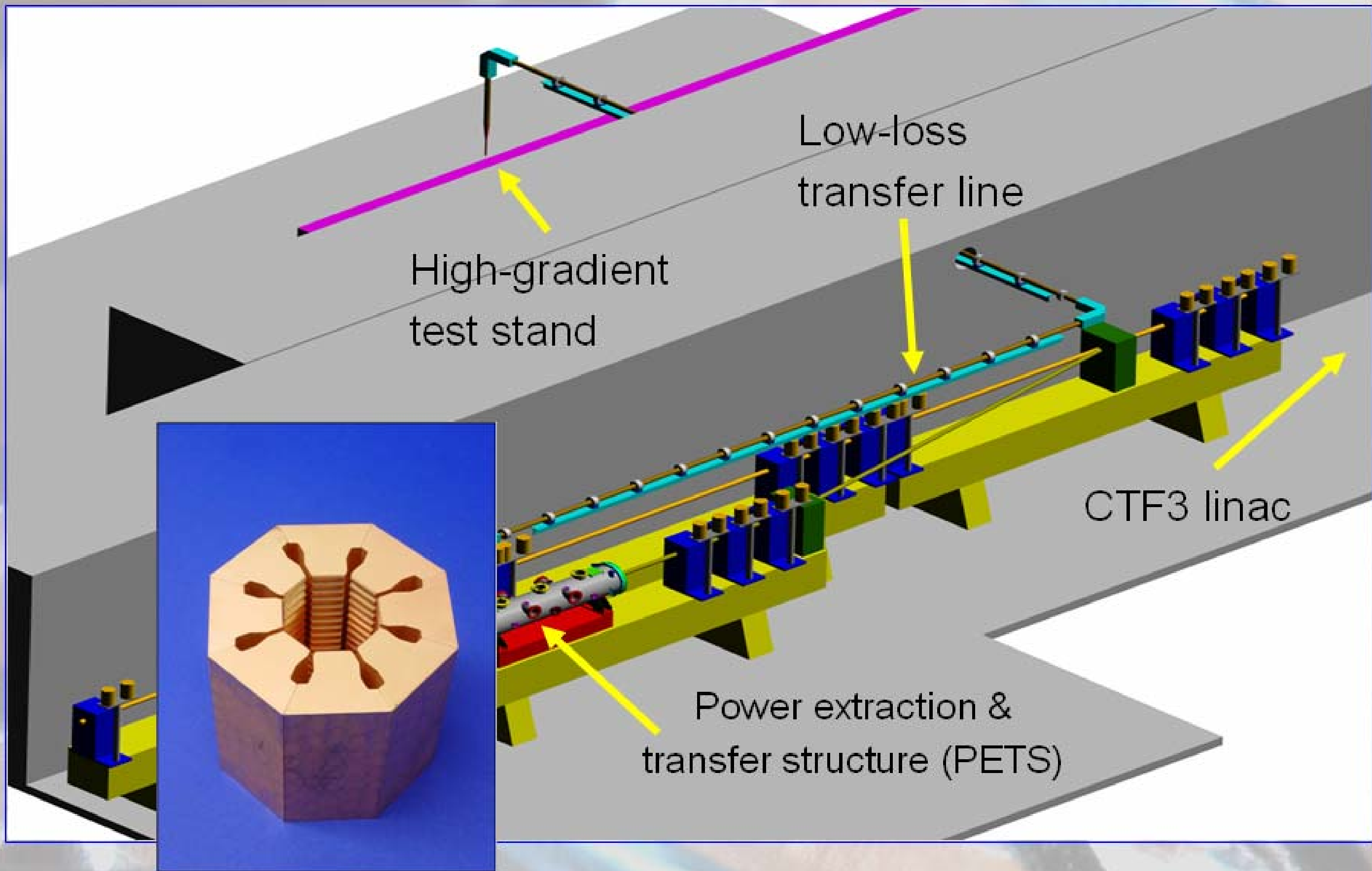
A 30-cell structure with Mo irises exceeded the CLIC accelerating field requirements without damage

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

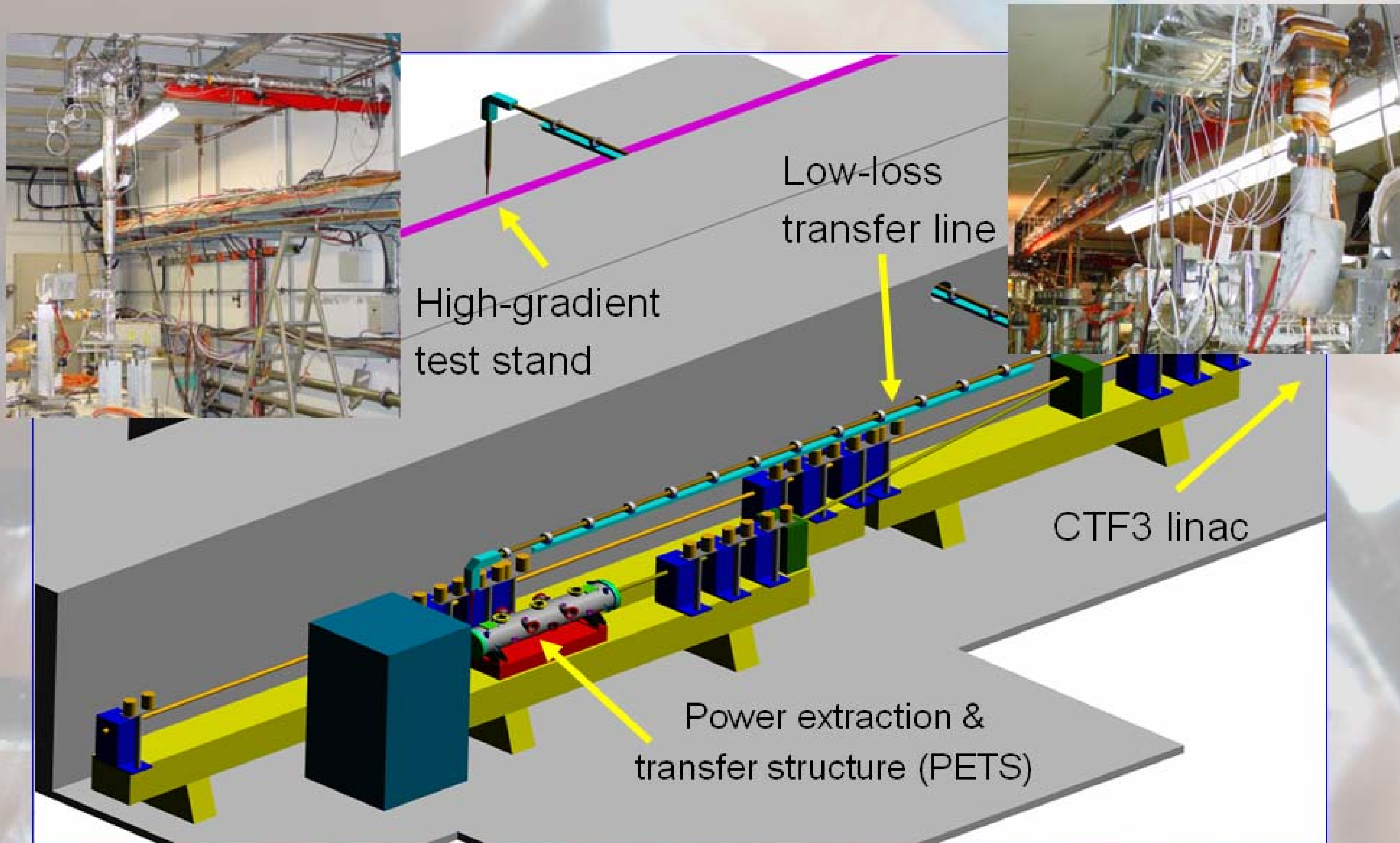
30 GHz Power production in CTF3



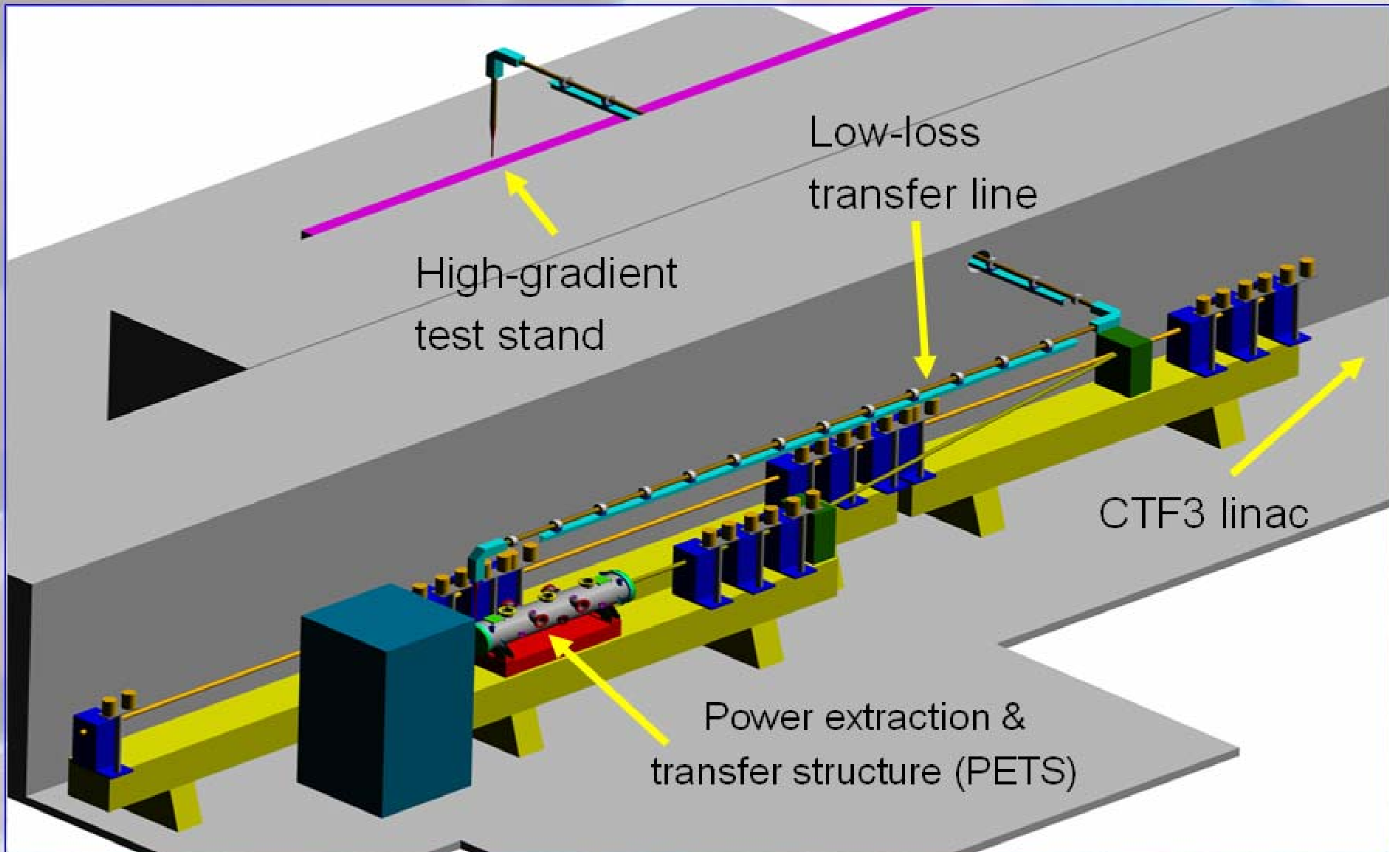
30 GHz Power production in CTF3



30 GHz Power production in CTF3



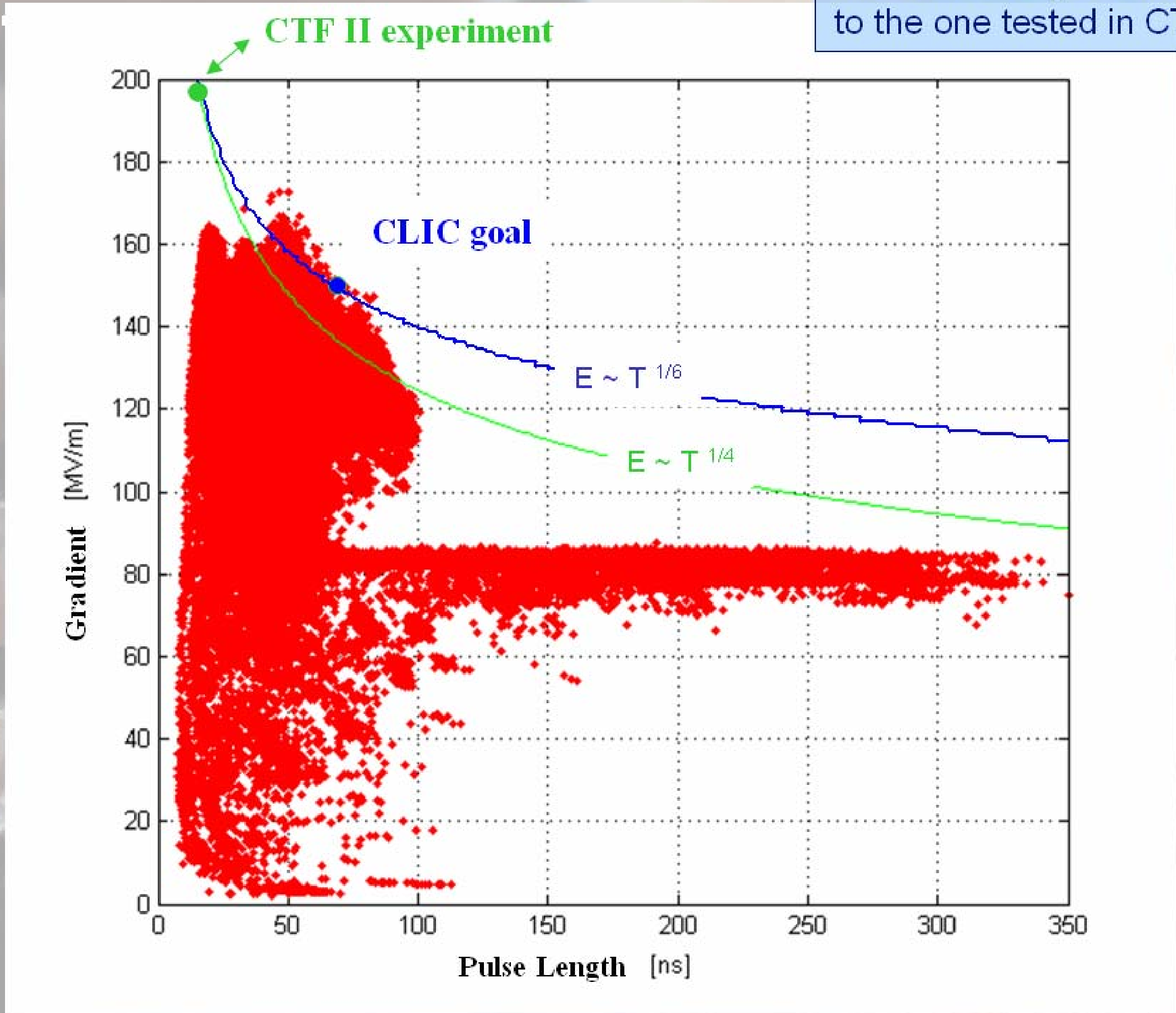
30 GHz Power production in CTF3



- Produced power up to about 100 MW – long pulses (up to 300 ns) available for the first time at 30 GHz
- Structure tests started in 2005 - 8 structures tested until now

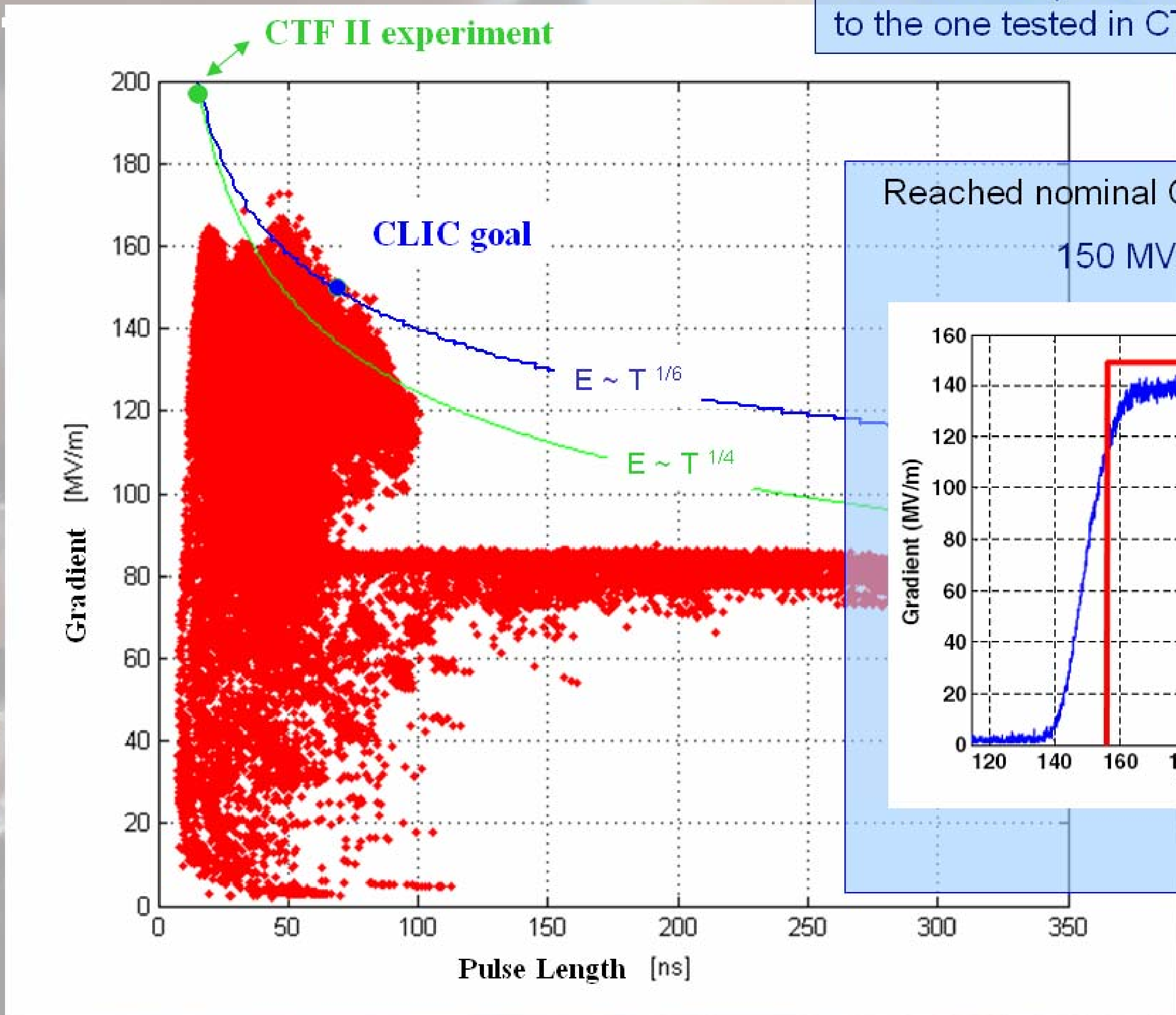
CTF3 High-Power test results – 30 GHz

Mo iris – clamped structure, identical to the one tested in CTF II



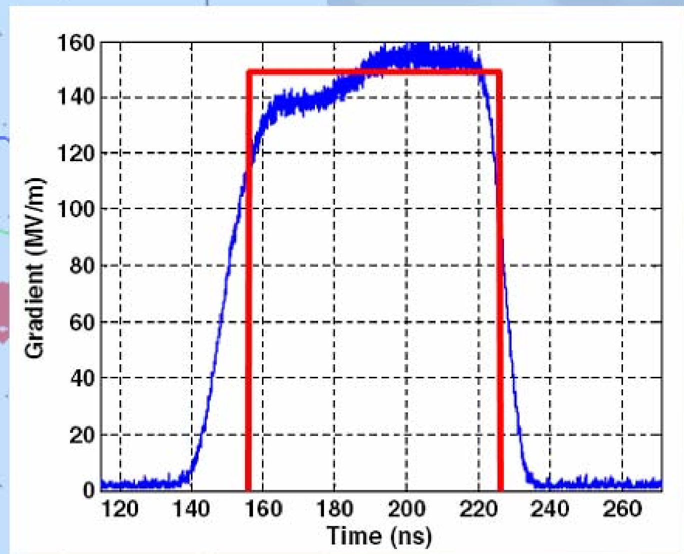
CTF3 High-Power test results – 30 GHz

Mo iris – clamped structure, identical to the one tested in CTF II



Reached nominal CLIC values :

150 MV/m - 70 ns



CTF3 High-Power test results – 30 GHz

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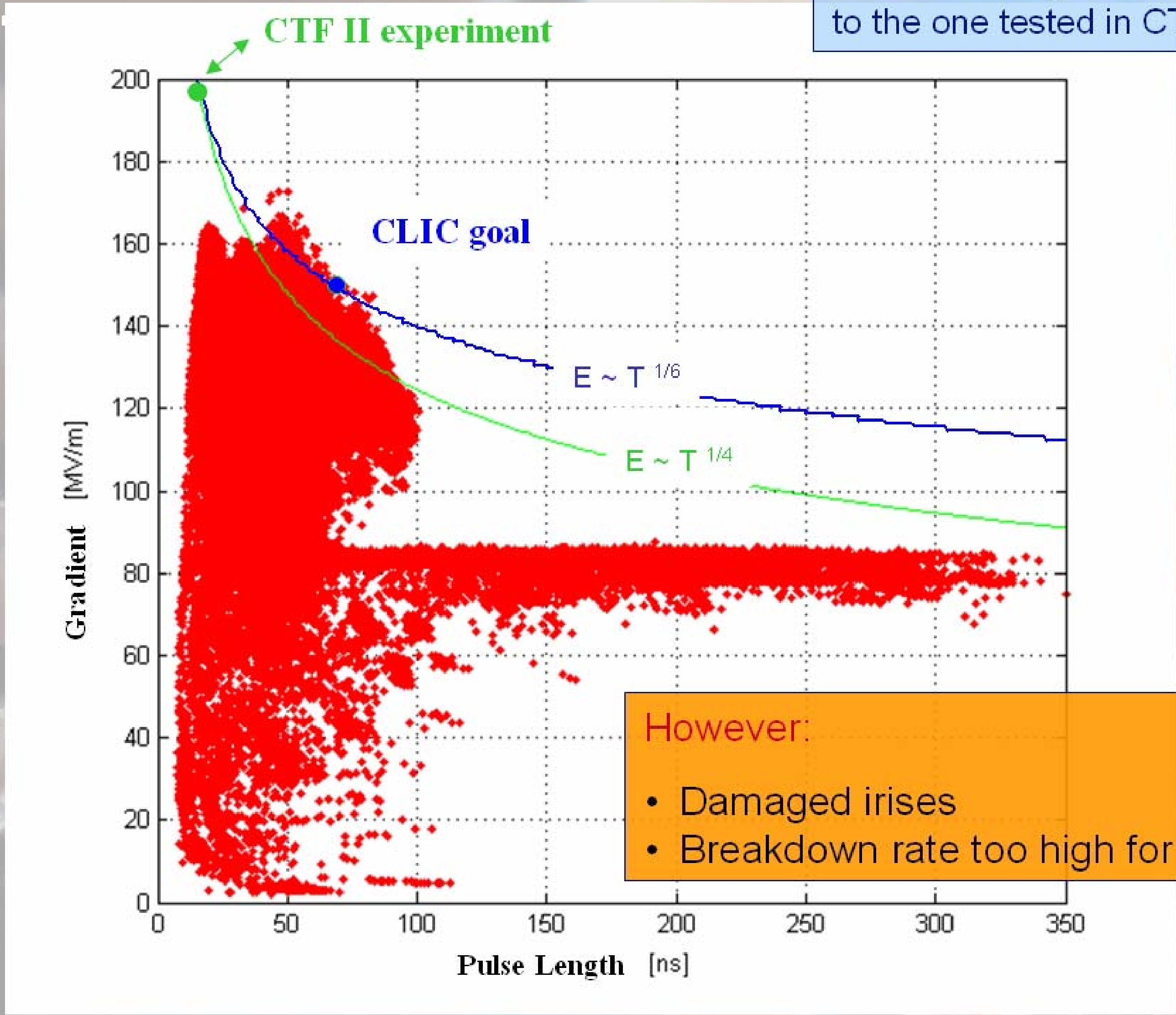
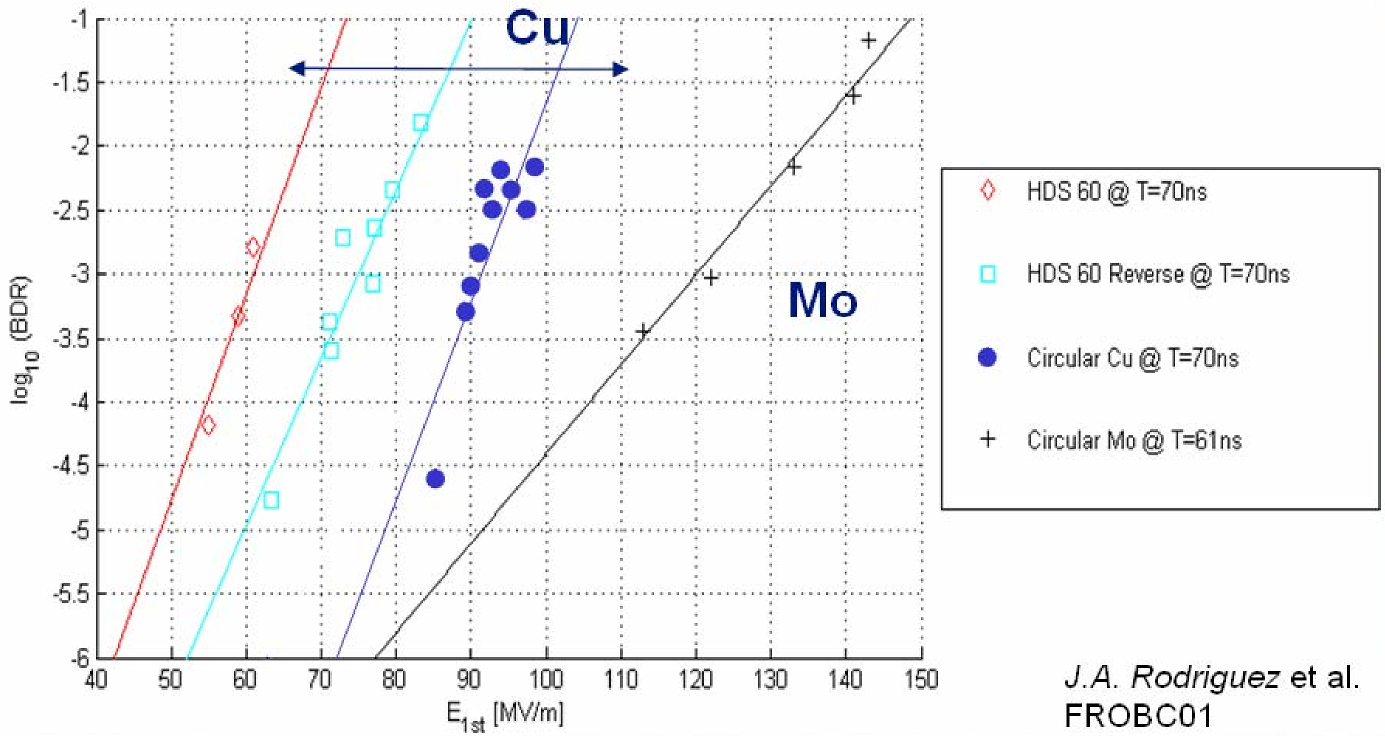


However:

- Damaged irises
- Breakdown rate too high for CLIC operation

CTF3 High-Power test results – 30 GHz

- Breakdown rate slope for Mo (and W) in general less steep than Cu
- Mo slope & conditioning limit not consistent in different tests…

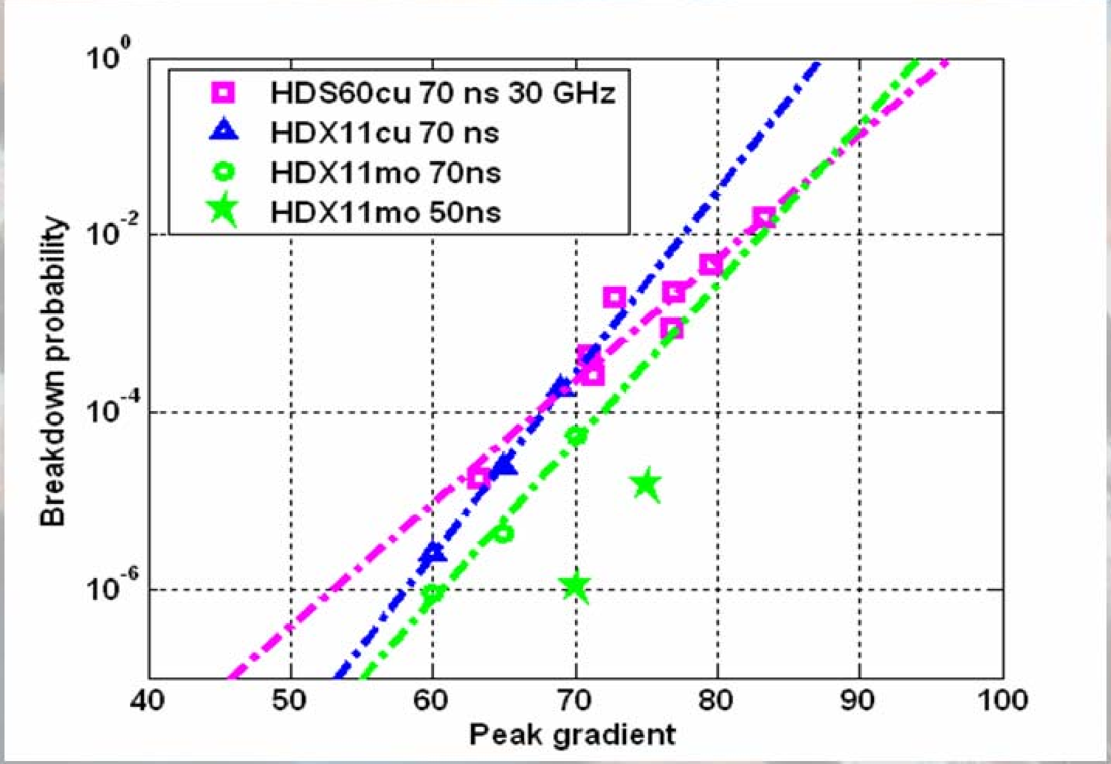


J.A. Rodriguez et al.
FROBC01

CTF3 - SLAC High-Power test results – 30 & 11.4 GHz

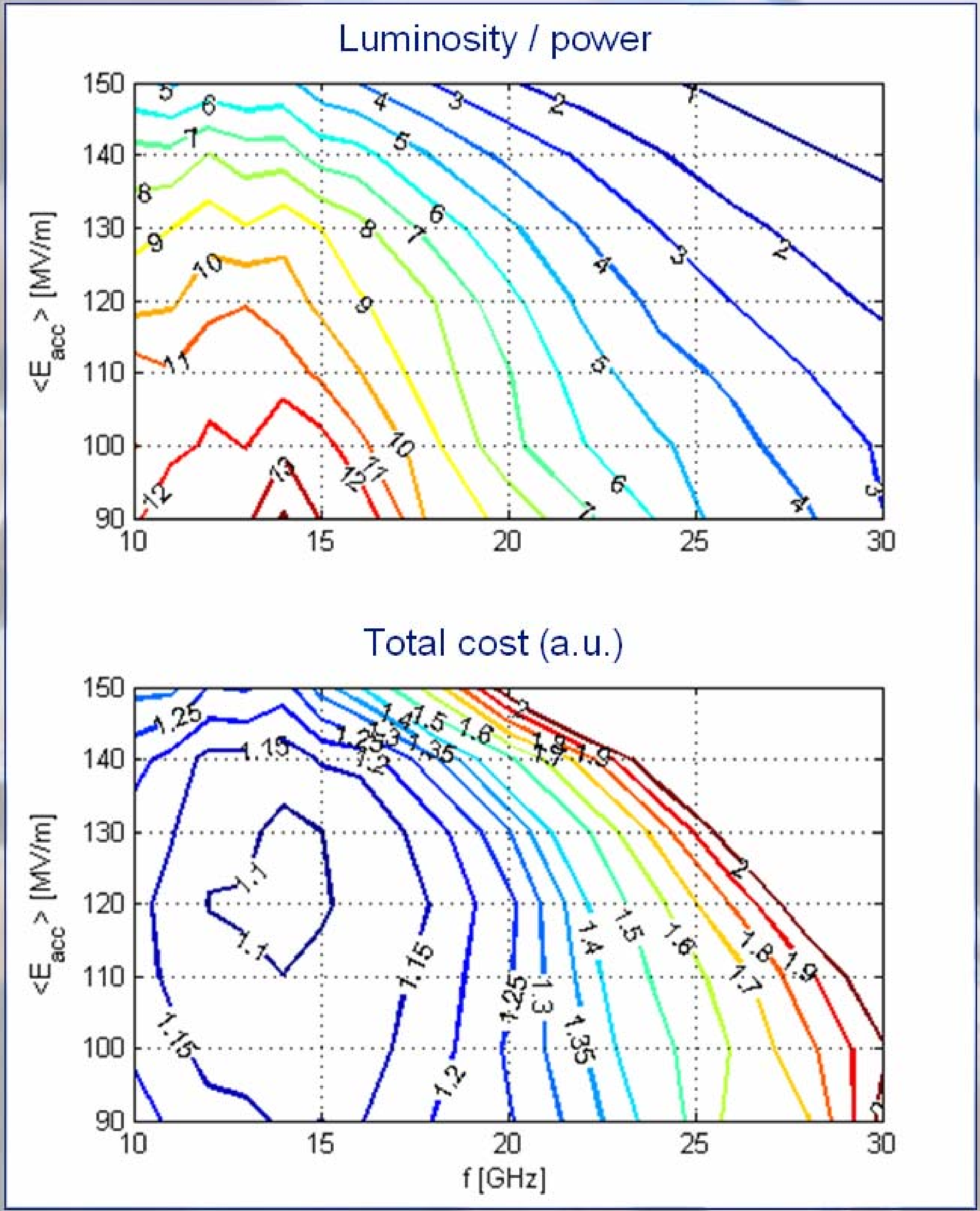
- Structures with scaled geometries at different frequencies have same performance

  Scaling introduced in a parametric model (taking into account RF structure & beam dynamics constraint), used to study optimum cost & efficiency



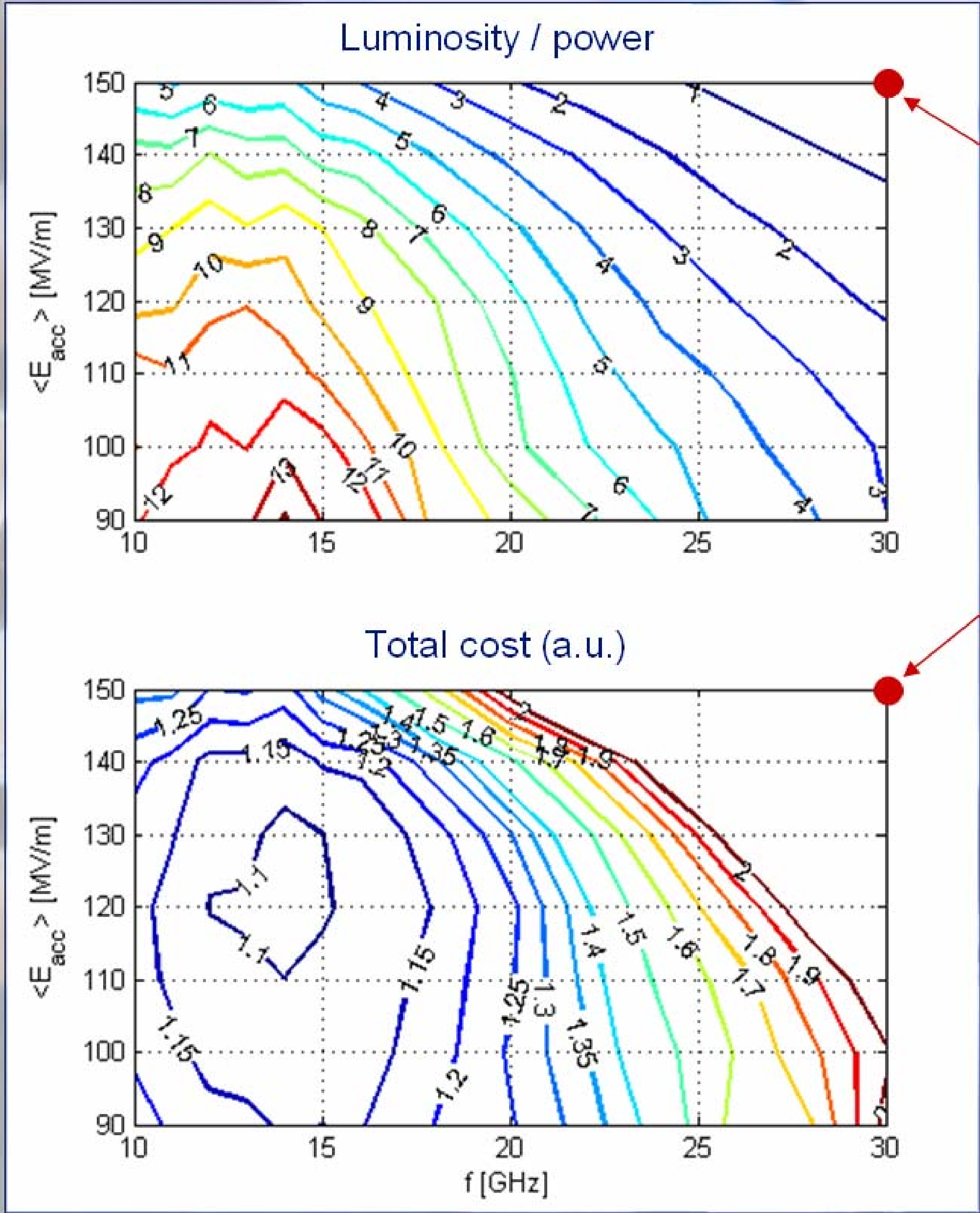
S. Doebert et al.
WEPMN070

Optimization results



A. Grudiev et al.
EPAC '06

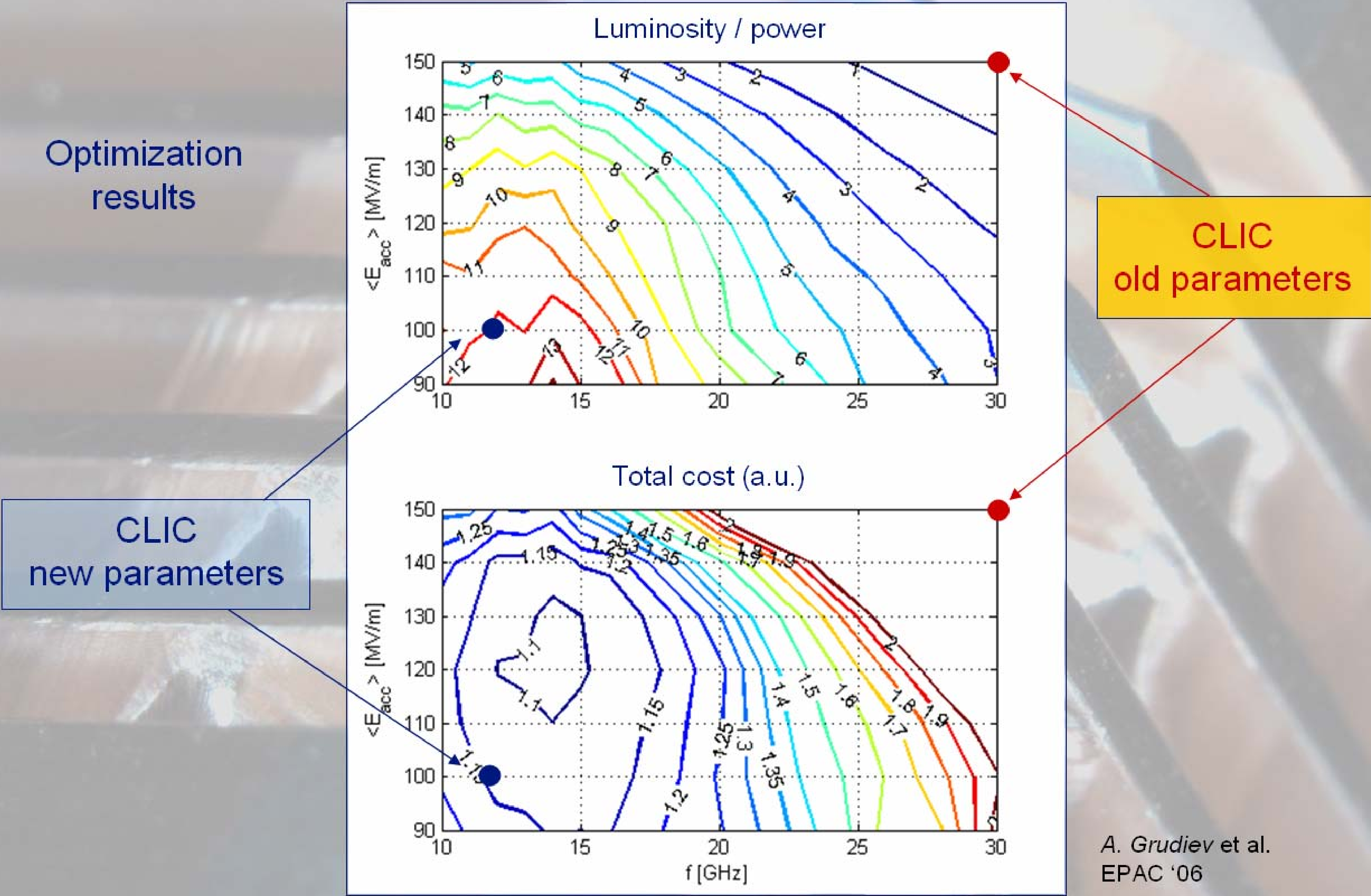
Optimization results



CLIC old parameters

A. Grudiev et al.
EPAC '06

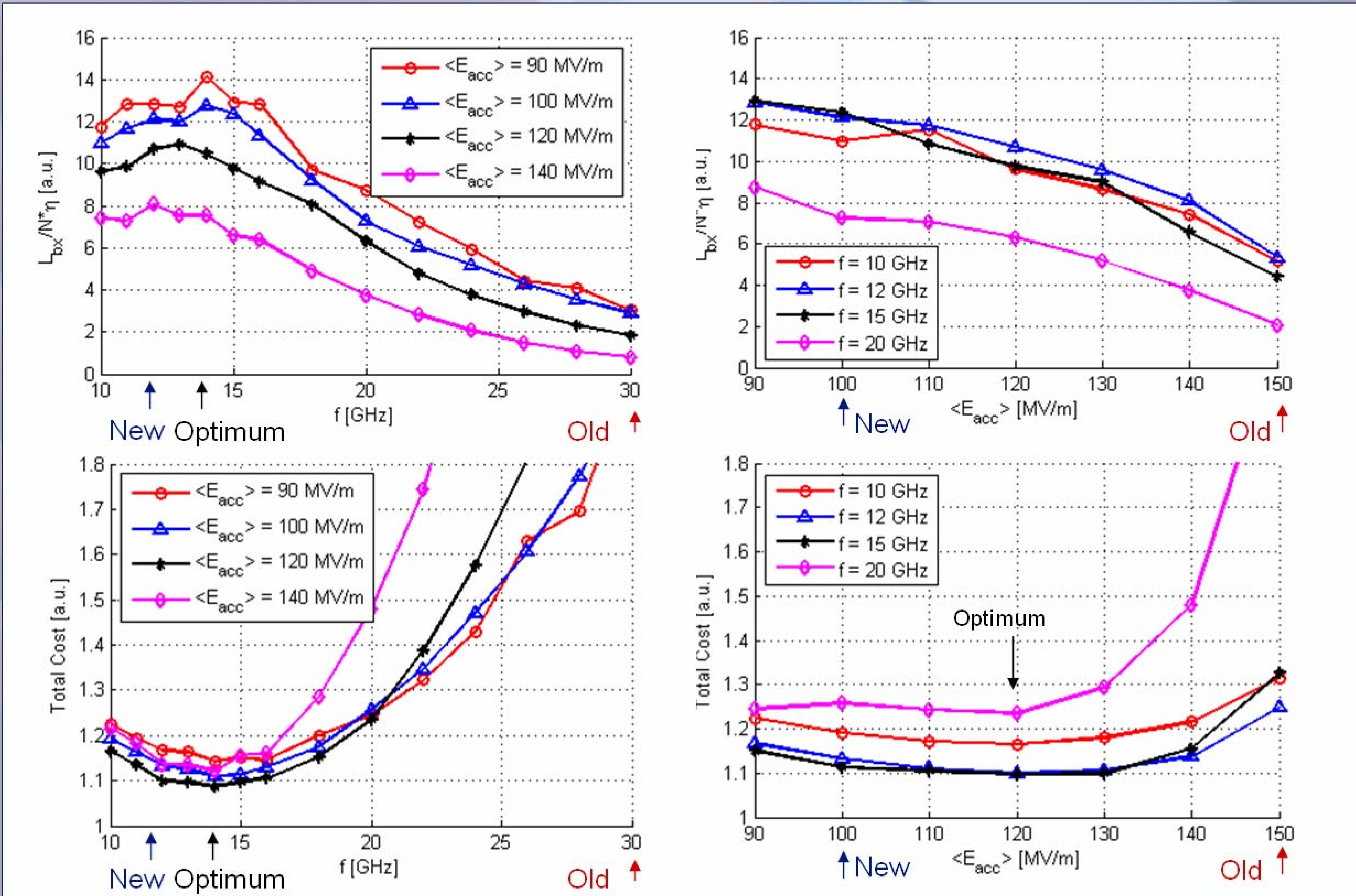
Optimization results



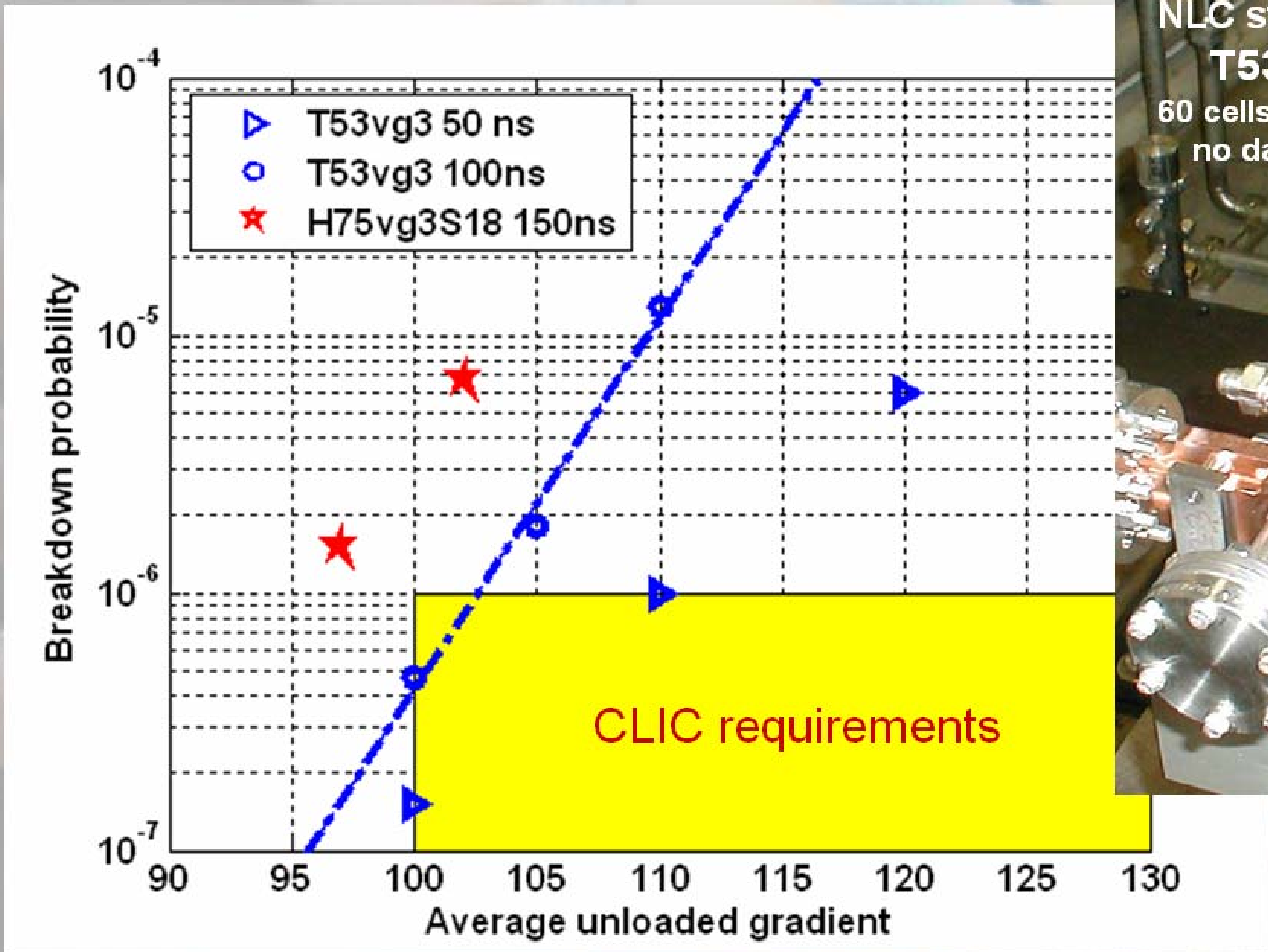
A. Grudiev et al.
EPAC '06

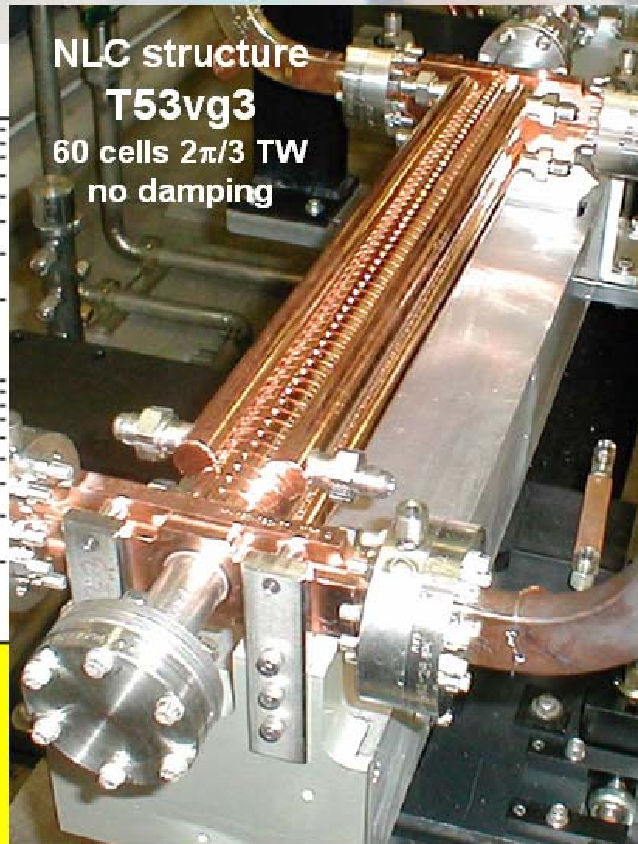
Results from CLIC proof of principle in CTF3

R. Corsini – PAC 07



Recent SLAC High-Power test results – 11.4 GHz





CLIC main parameters

Center-of-mass energy	3 TeV
Peak Luminosity	7 10^{34} cm^{-2} s^{-1}
Peak luminosity (in 1% of energy)	2 10^{34} cm^{-2} s^{-1}
Repetition rate	50 Hz
Loaded accelerating gradient	100 MV/m
Main linac RF frequency	12 GHz
Overall two-linac length	41.7 km
Bunch charge	4 10^{9}
Beam pulse length	200 ns
Average current in pulse	1 A
Hor./vert. normalized emittance	660 / 20 nm rad
Hor./vert. IP beam size before pinch	53 / ~1 nm
Total site length	48.25 km
Total power consumption	390 MW

Provisional values

CLIC main parameters

NEW

Center-of-mass energy	3 TeV
Peak Luminosity	$7\ 10^{34}$ cm^{-2} s^{-1}
Peak luminosity (in 1% of energy)	$2\ 10^{34}$ cm^{-2} s^{-1}
Repetition rate	50 Hz
Loaded accelerating gradient	100 MV/m
Main linac RF frequency	12 GHz
Overall two-linac length	41.7 km
Bunch charge	$4\ 10^{9}$
Beam pulse length	200 ns
Average current in pulse	1 A
Hor./vert. normalized emittance	660 / 20 nm rad
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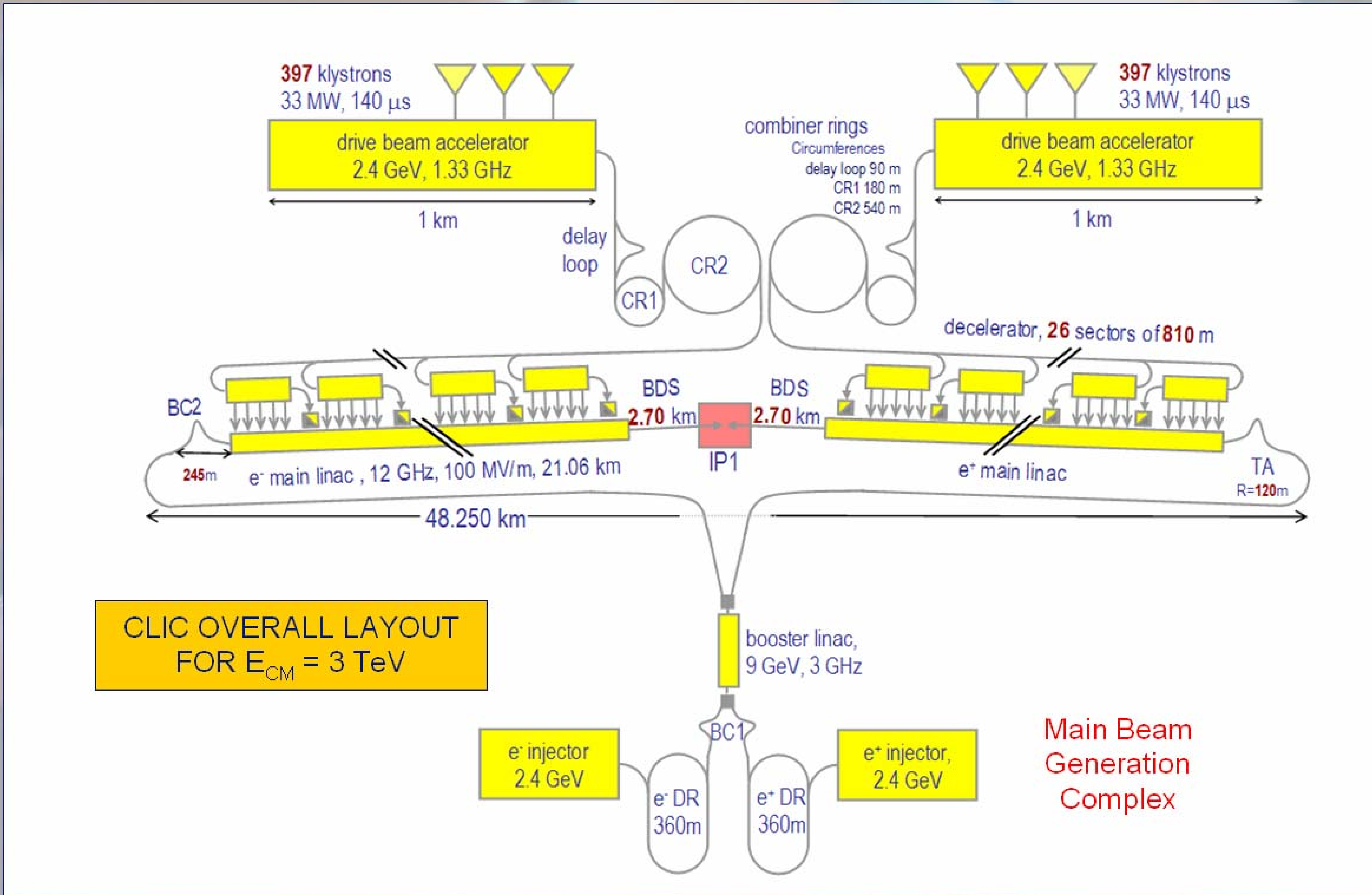
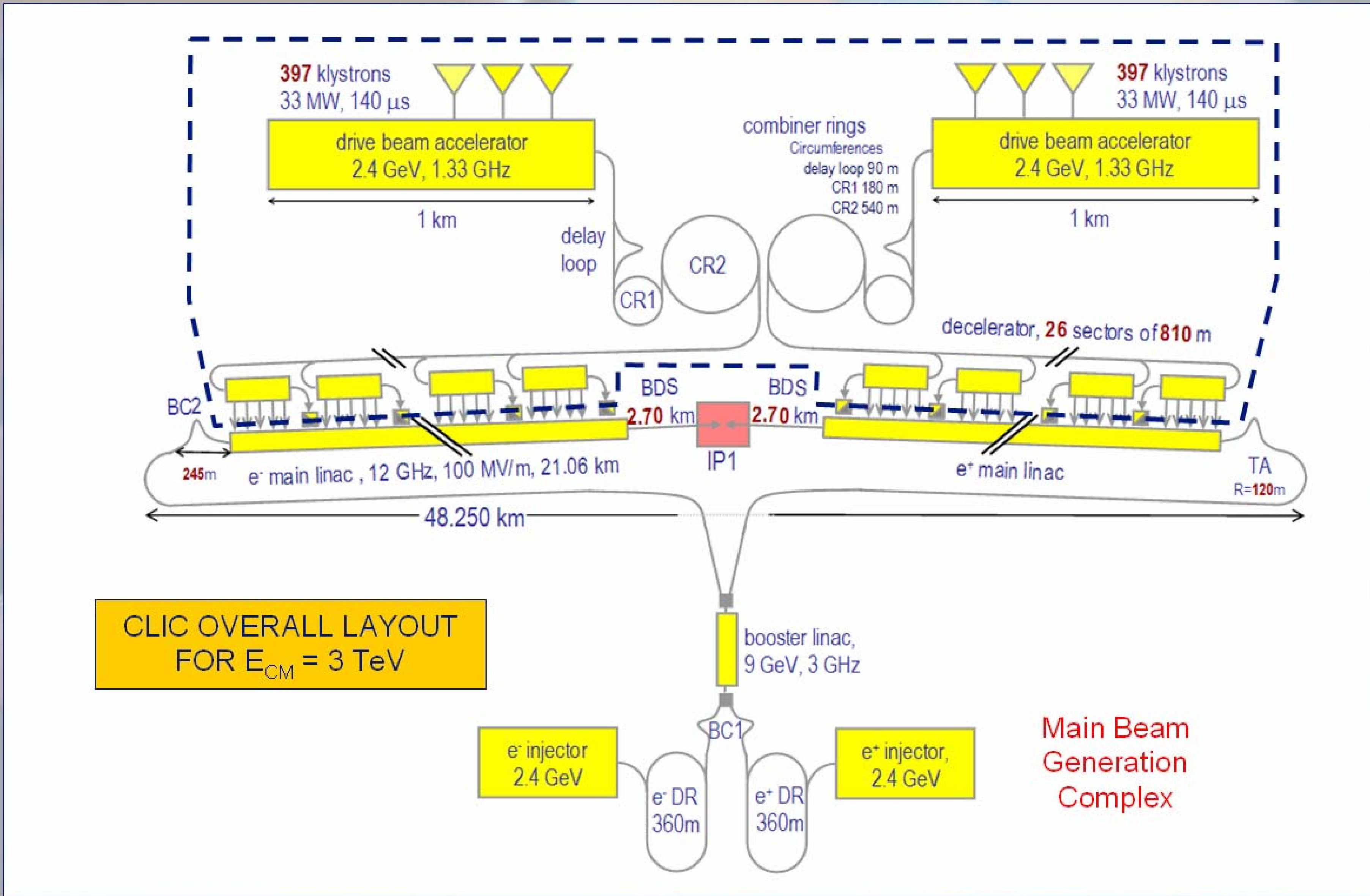
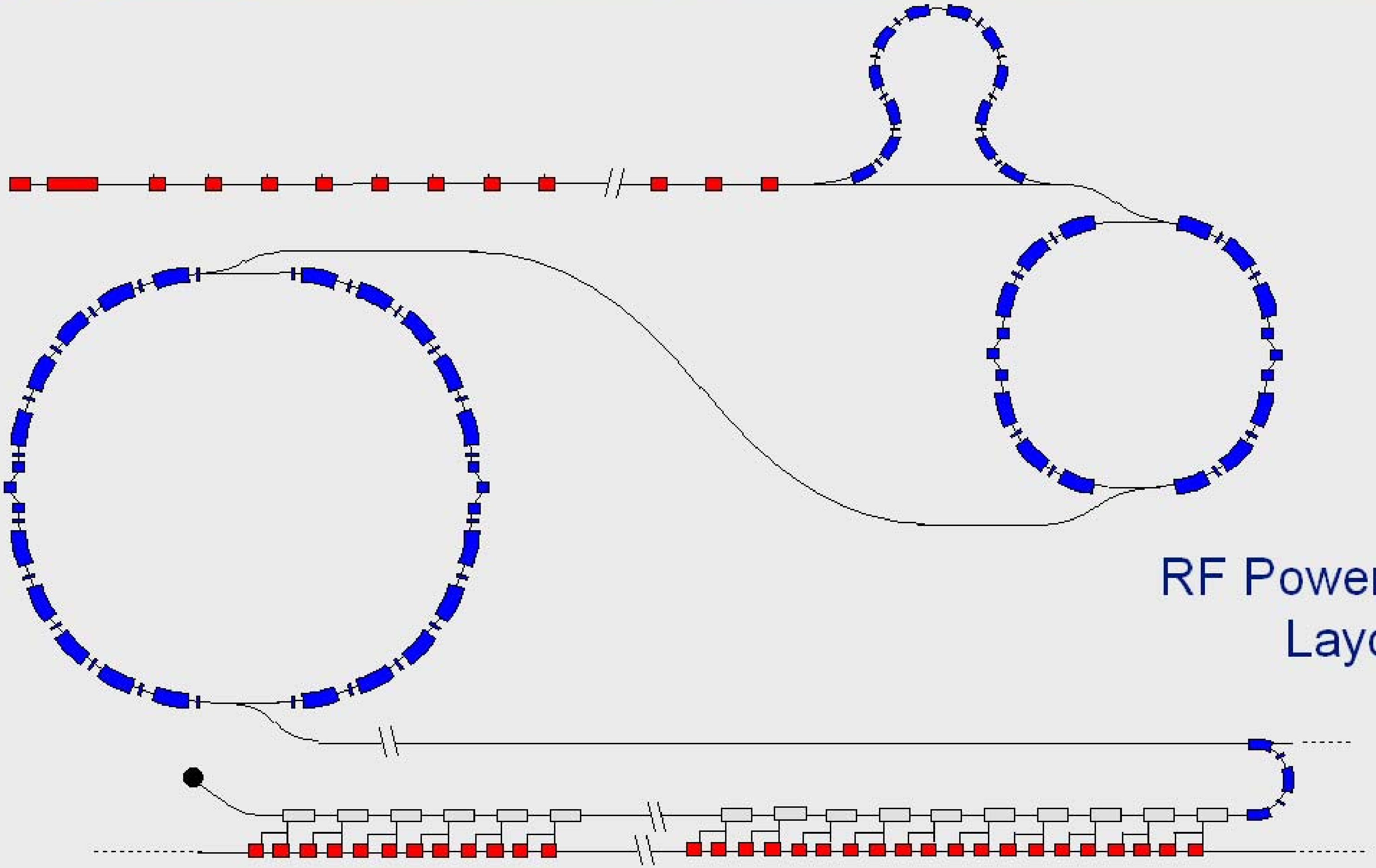
Provisional values


397 klystrons
33 MW, 140 μs
drive beam accelerator
2.4 GeV, 1.33 GHz
1 km
combiner rings
Circumferences
delay loop 90 m
CR1 180 m
CR2 540 m
397 klystrons
33 MW, 140 μs
drive beam accelerator
2.4 GeV, 1.33 GHz
1 km
delay loop
CR1
CR2
decelerator, 26 sectors of 810 m
BC2
BDS
2.70 km
BDS
2.70 km
IP1
245m
e- main linac , 12 GHz, 100 MV/m, 21.06 km
e+ main linac
TA
R=120m
48.250 km
CLIC OVERALL LAYOUT
FOR E$_{CM}$ = 3 TeV
booster linac,
9 GeV, 3 GHz
BC1
e- injector
2.4 GeV
e- DR
360m
e+ DR
360m
e+ injector,
2.4 GeV
Main Beam
Generation
Complex

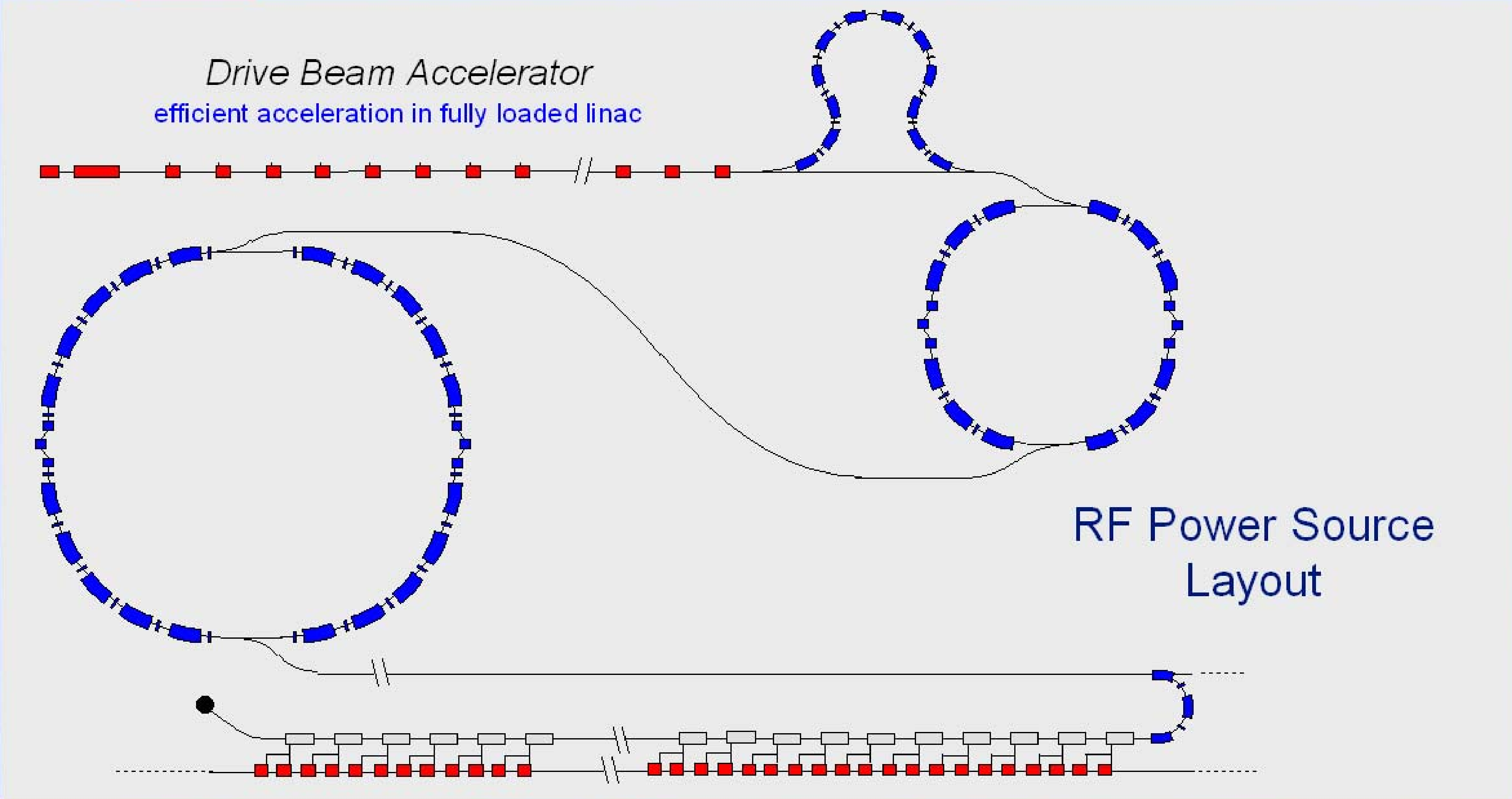
CLIC RF power source



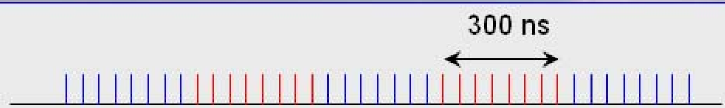


RF Power Source Layout

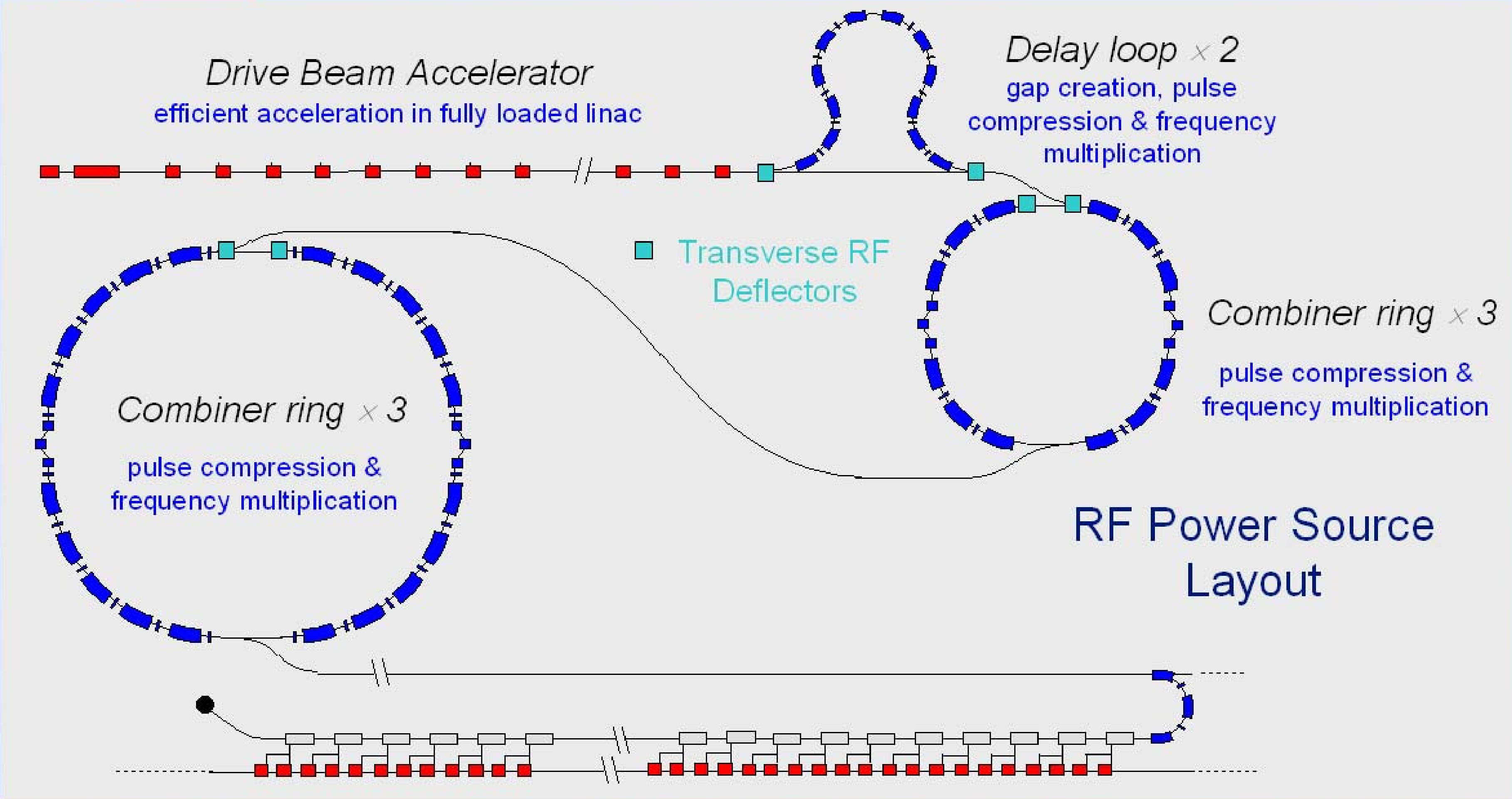
Results from CLIC proof of principle in CTF3



Drive beam time structure - initial



140 µs total length - 18 × 26 sub-pulses - 5.2 A
2.4 GeV - 45 cm between bunches



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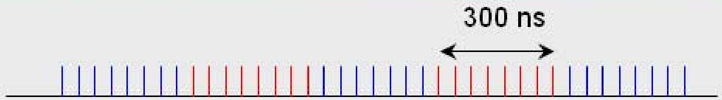

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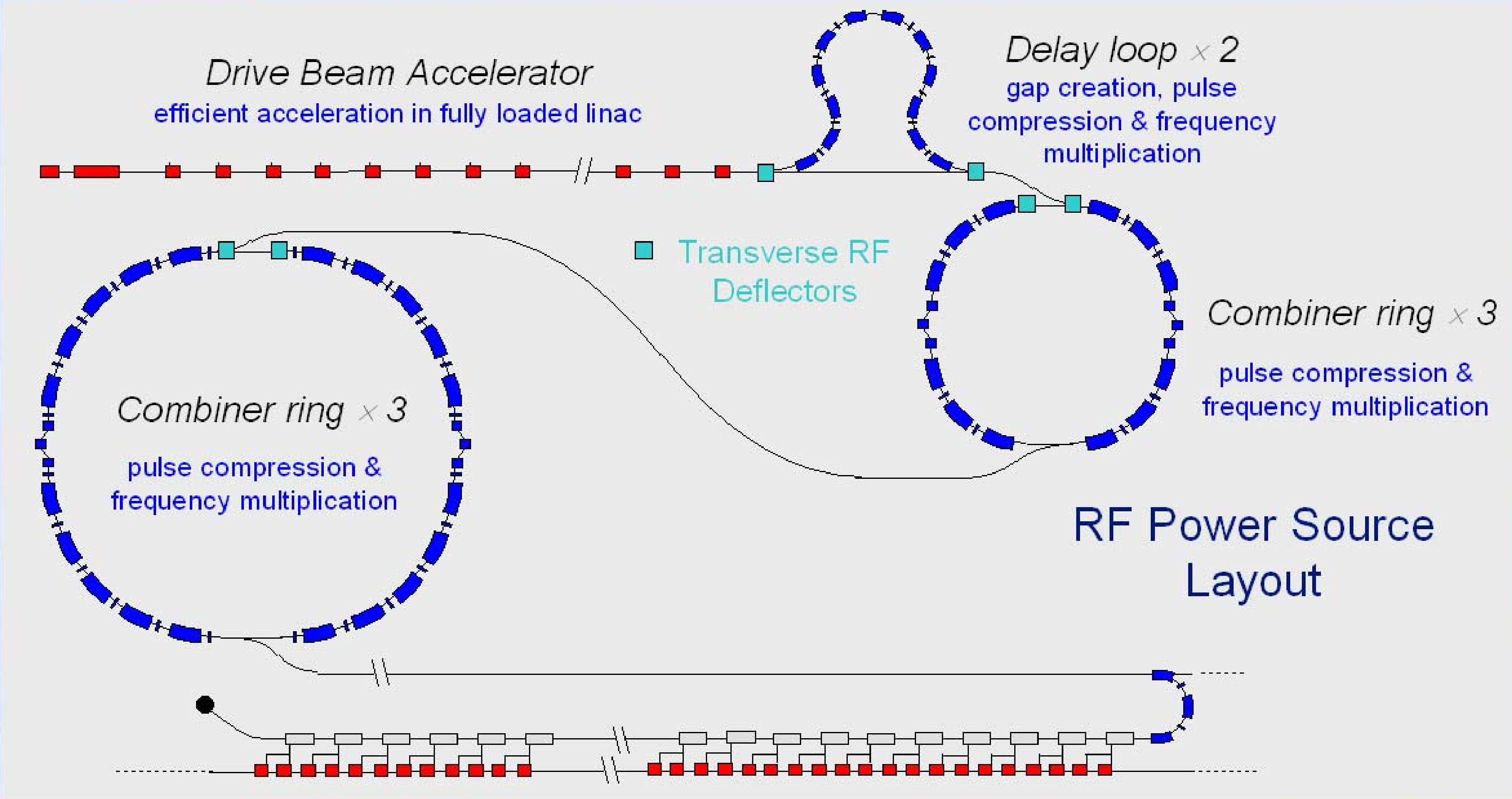

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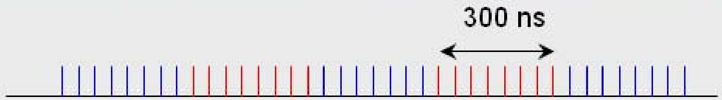

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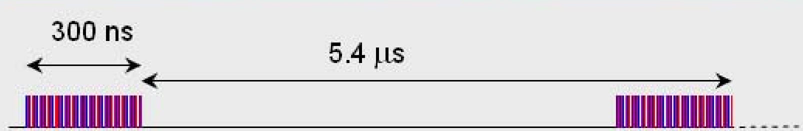
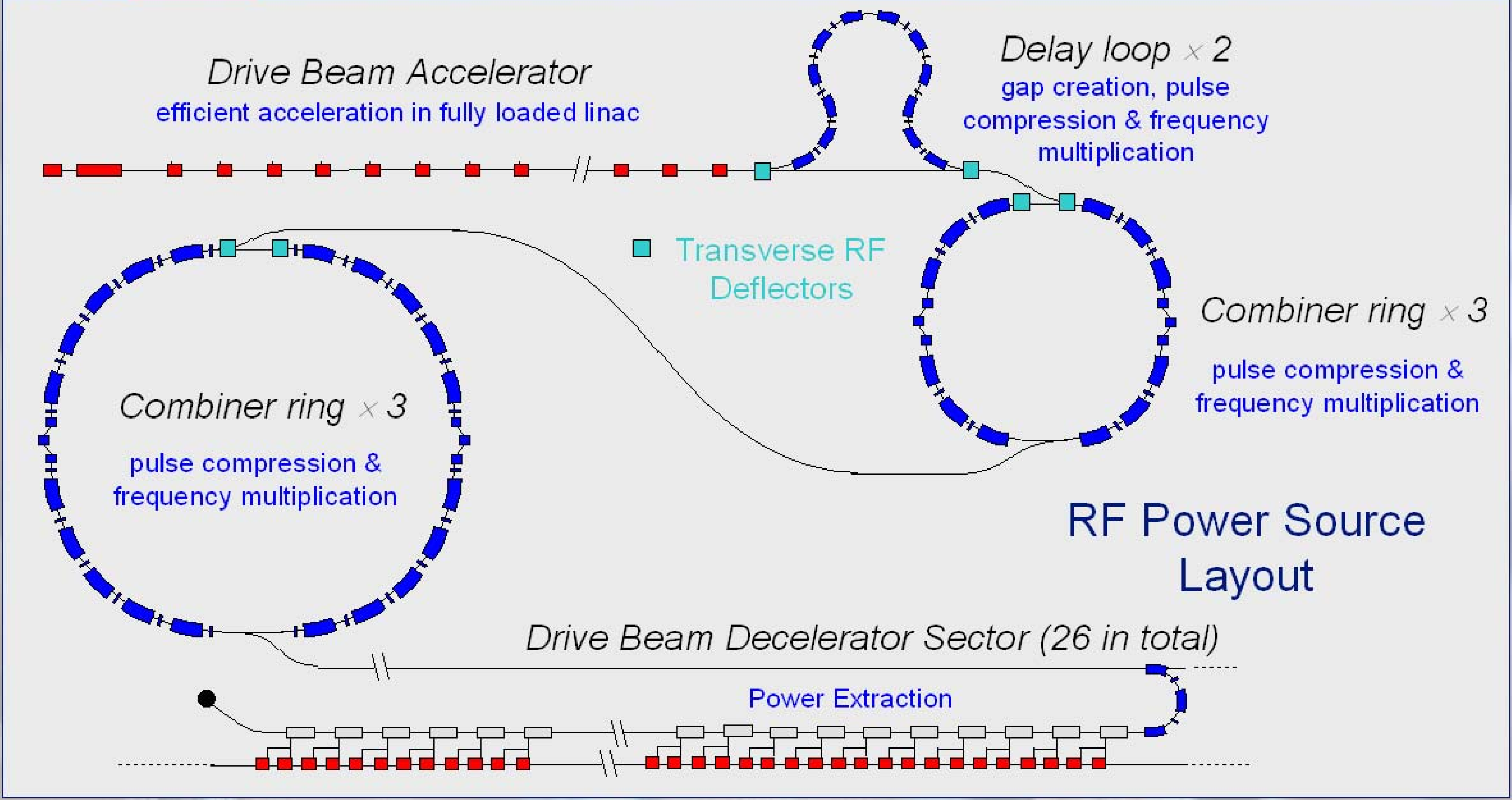
Drive beam time structure - final

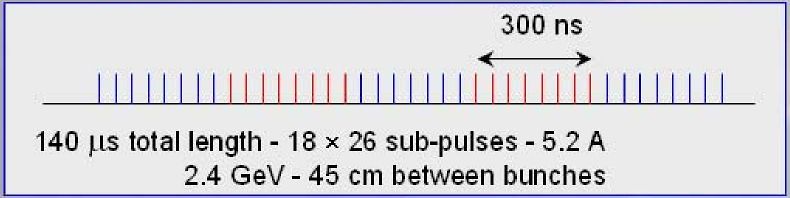


26 pulses – 93 A – 2.5 cm between bunches

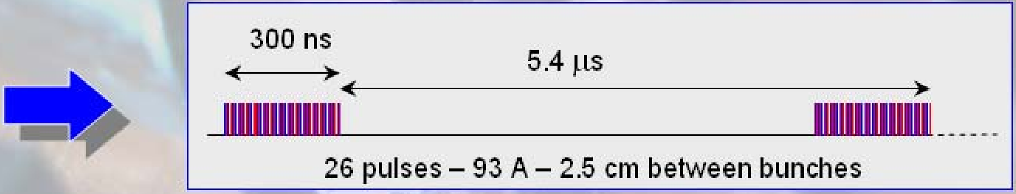
Results from CLIC proof of principle in CTF3



Drive beam time structure - initial



Drive beam time structure - final



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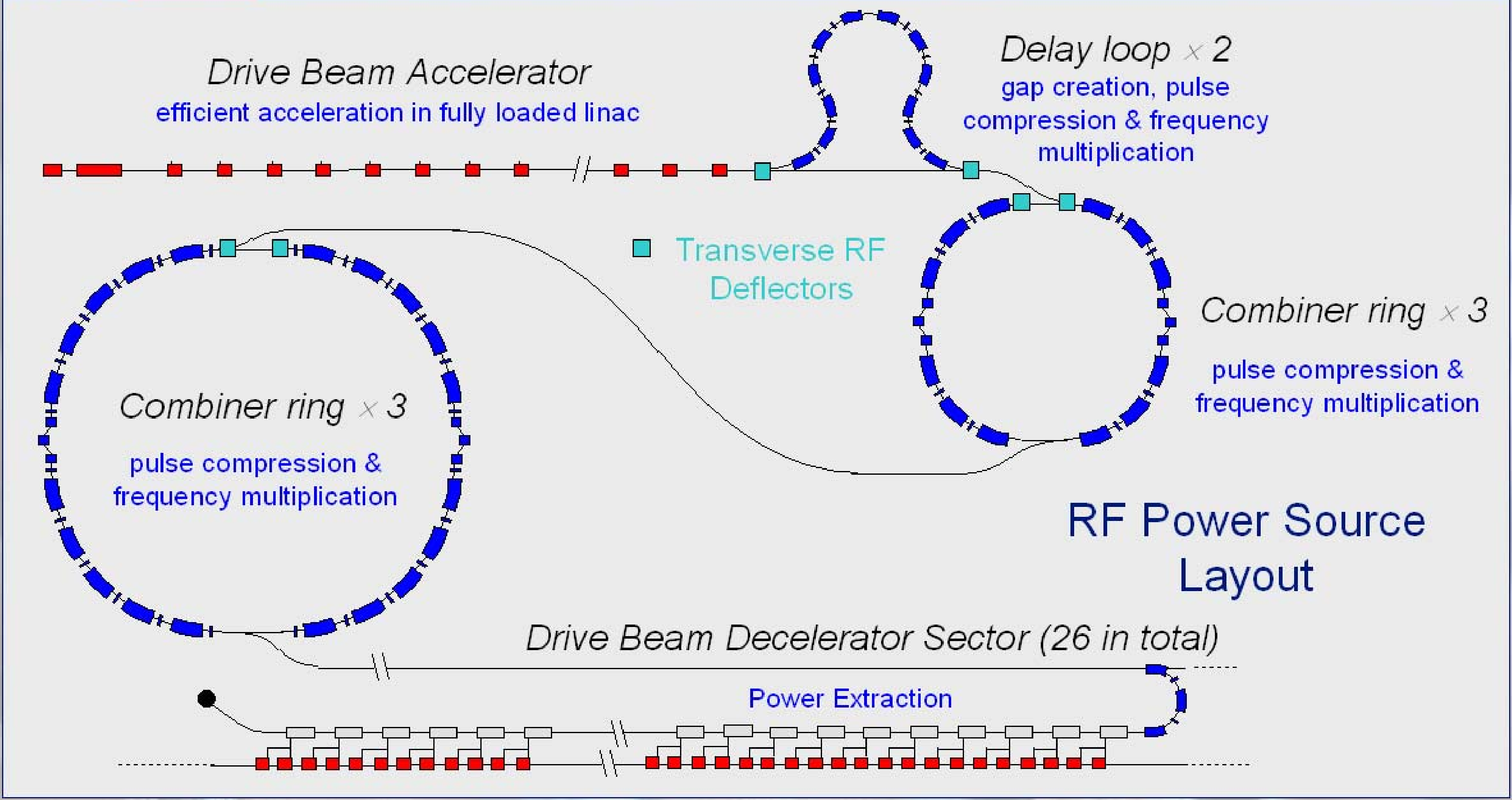

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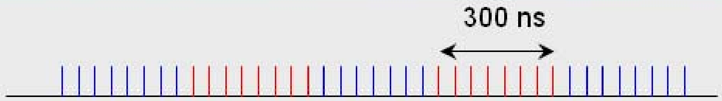

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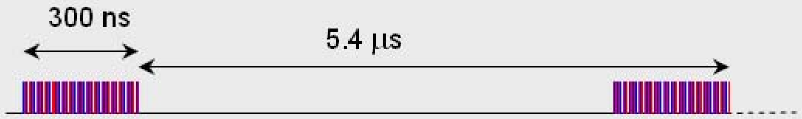


26 pulses – 93 A – 2.5 cm between bunches

Motivation and goals of CTF3 collaboration

Build a small-scale version of the CLIC RF power source, in order to demonstrate:

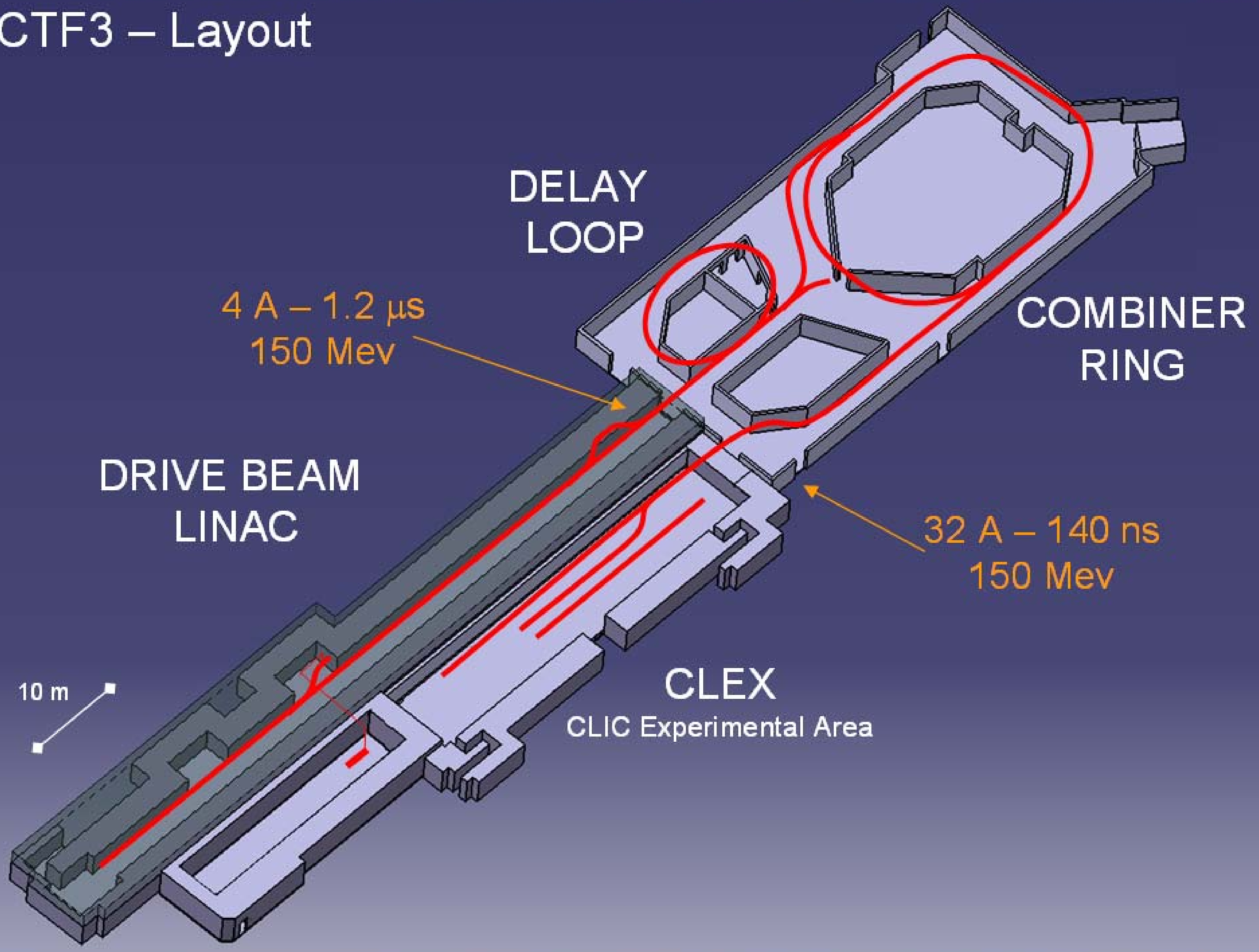
- ✓ full beam loading accelerator operation
- ✓ electron beam pulse compression and frequency multiplication using RF deflectors

Provide the RF power to test the CLIC accelerating structures and components

CTF3 is being built at CERN by a collaboration modeled on the large physics experiments

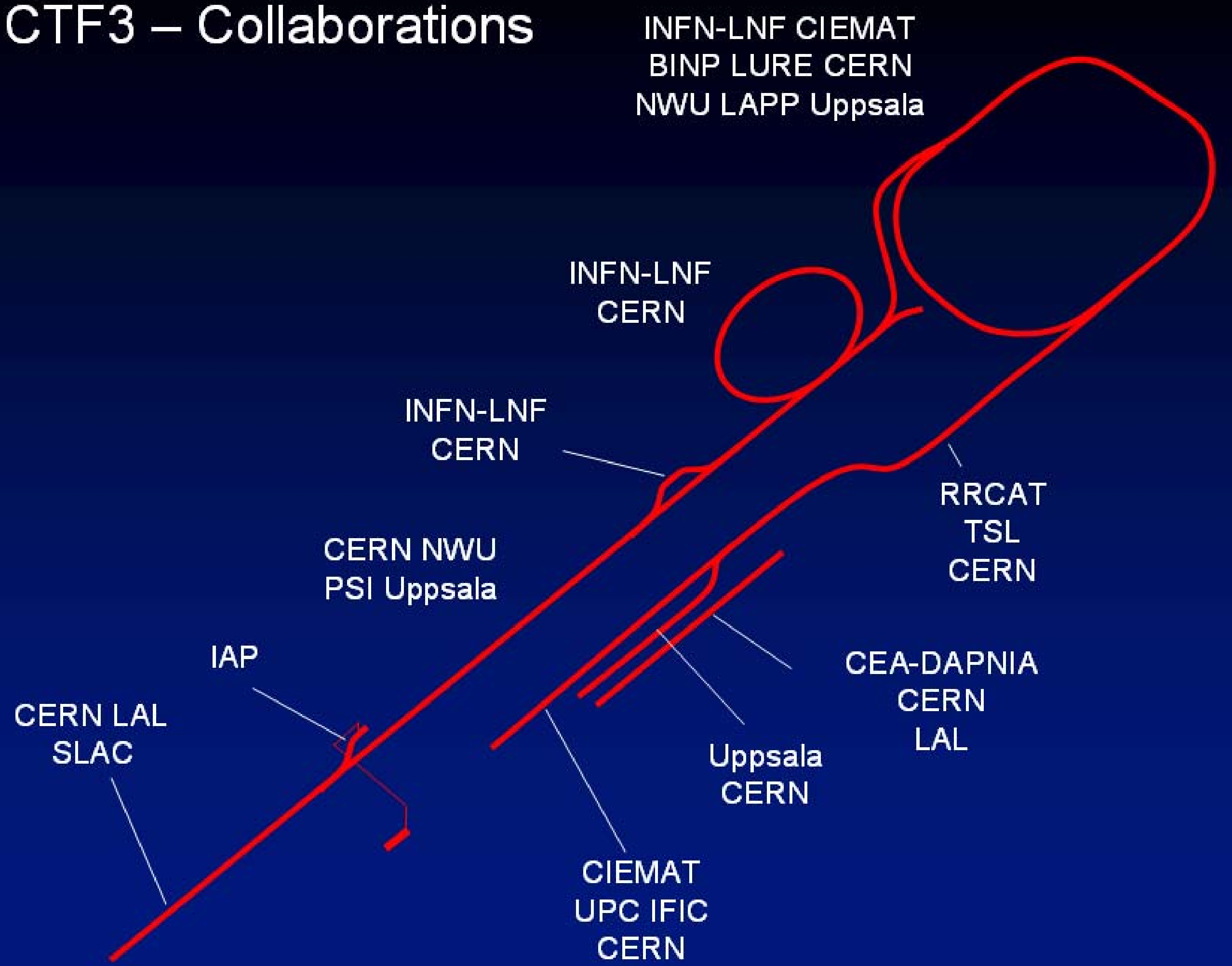
20 institutes from 11 countries
Chairman of collaboration Board: M. Calvetti (INFN-LNF)
Spokesperson: G. Geschonke (CERN)

CTF3 – Layout

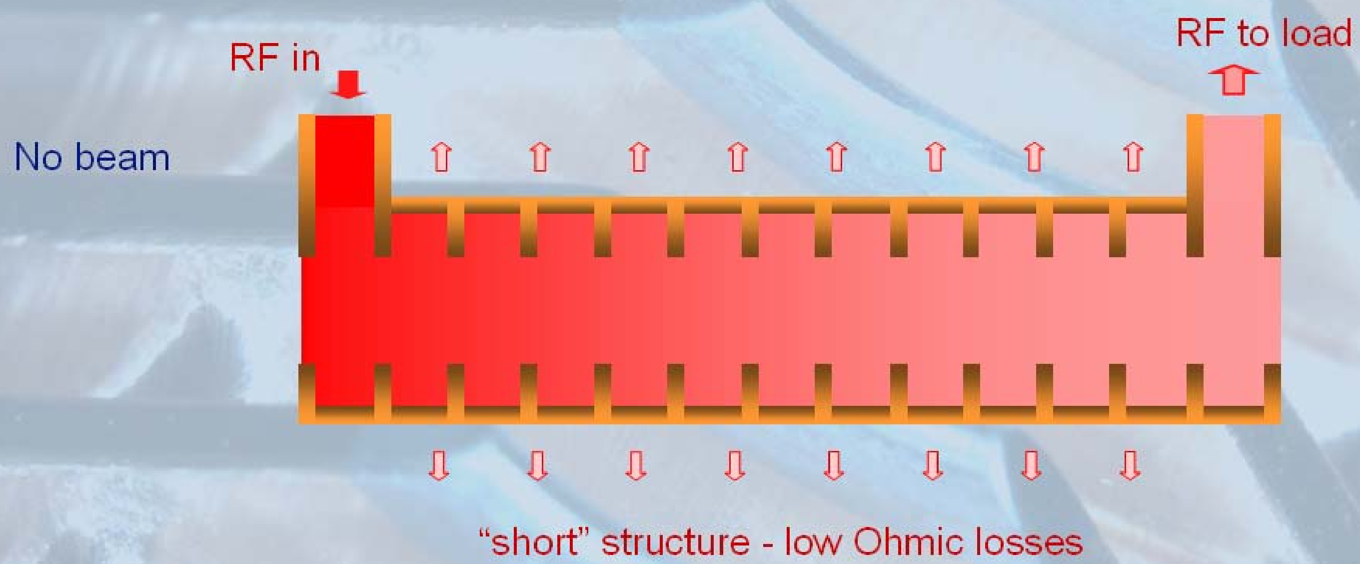

DELAY LOOP
4 A – 1.2 μs
150 Mev
COMBINER RING
DRIVE BEAM LINAC
32 A – 140 ns
150 Mev
10 m
CLEX
CLIC Experimental Area

CTF3 – Main components

CTF3 – Collaborations



Full beam-loading acceleration in TW sections



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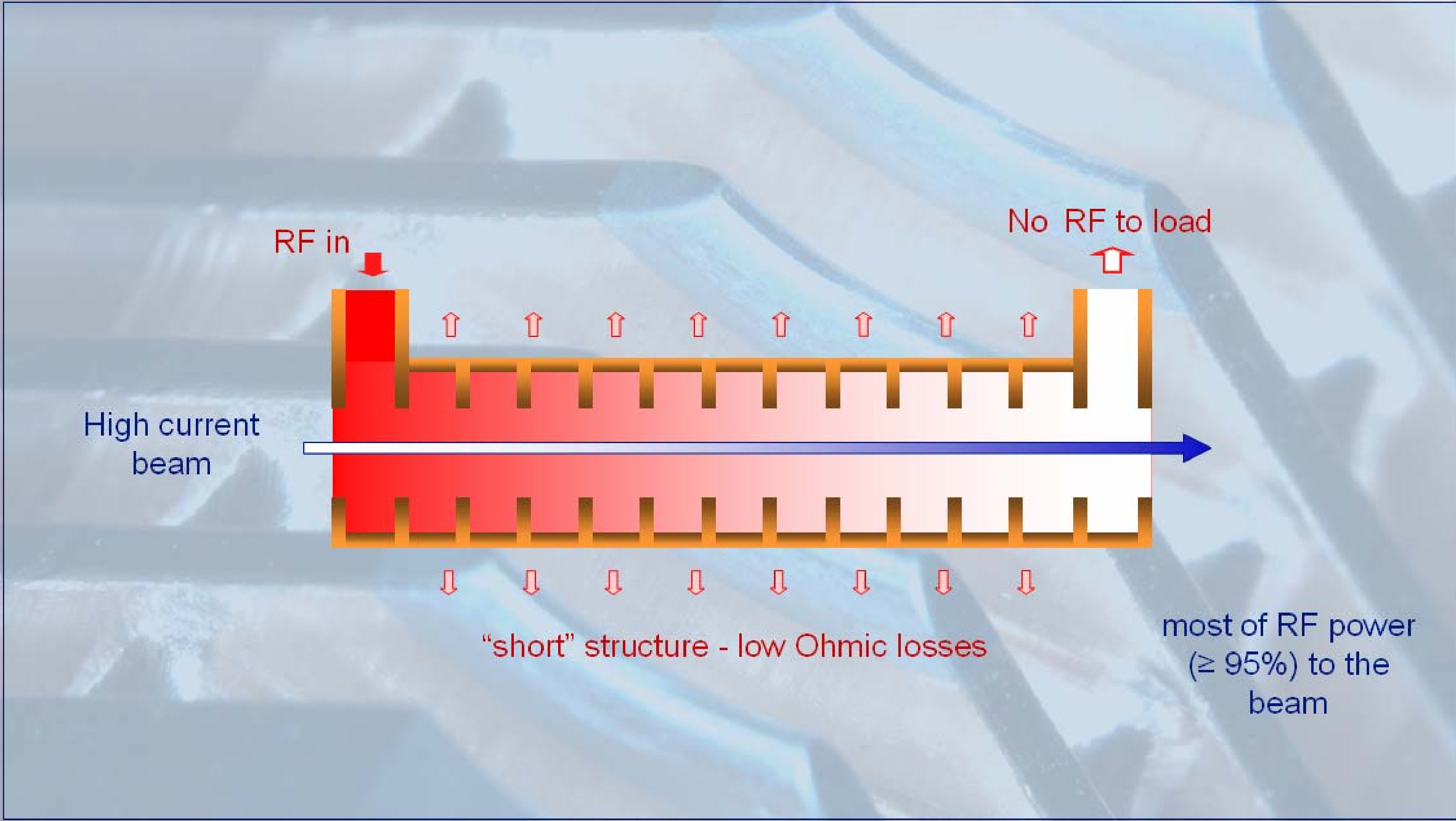

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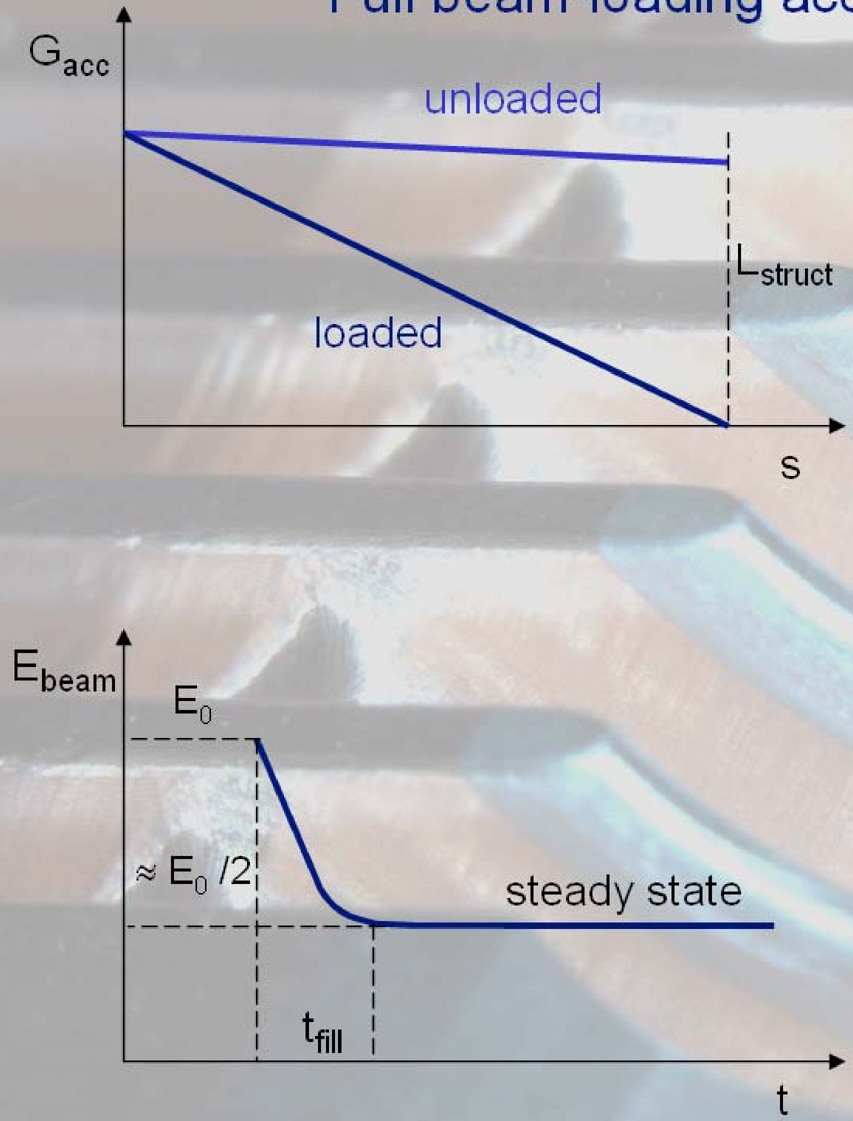
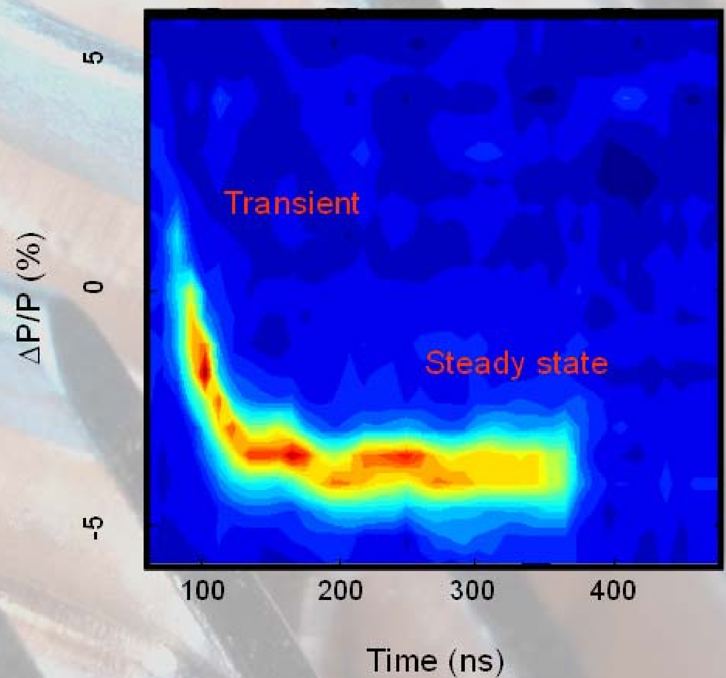


Time resolved beam energy spectrum measurement in CTF3



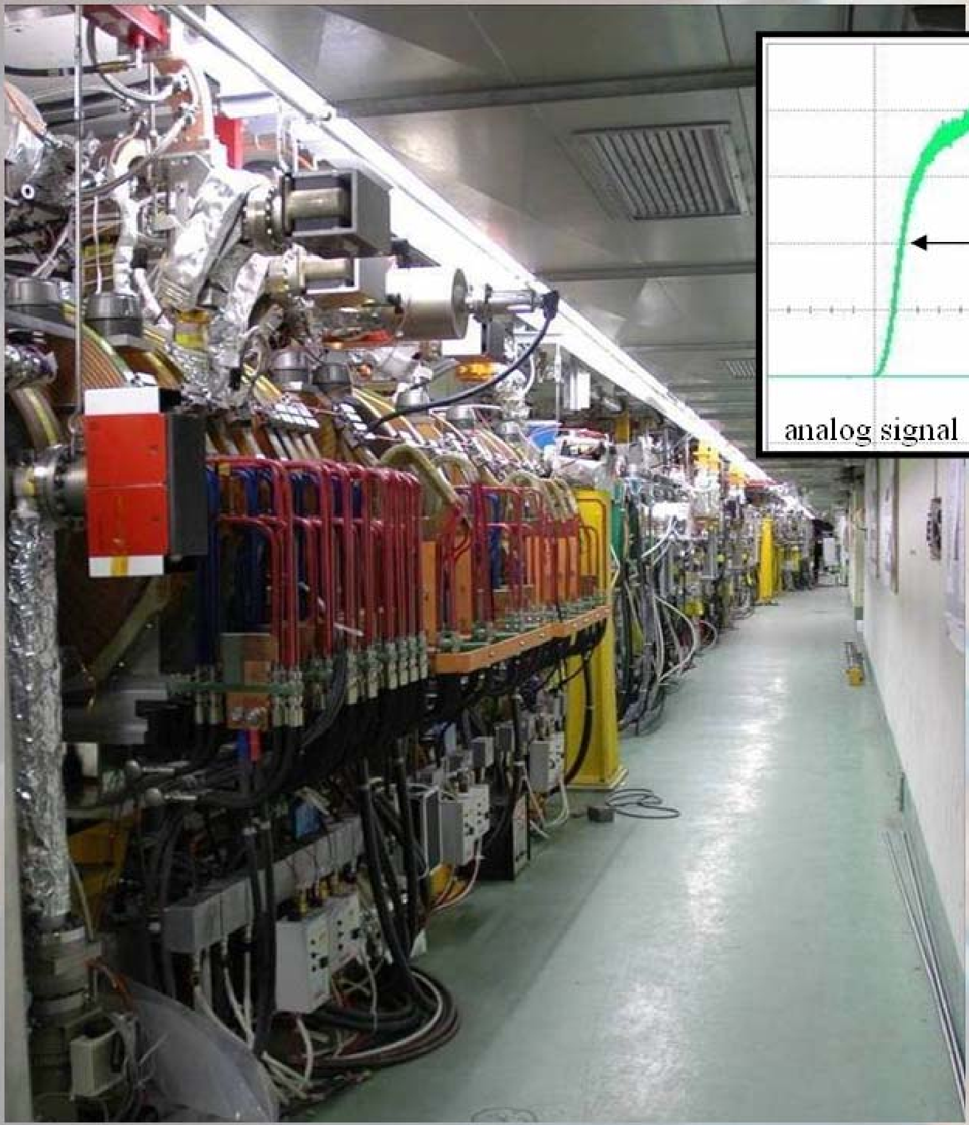
CTF3 linac accelerating structures

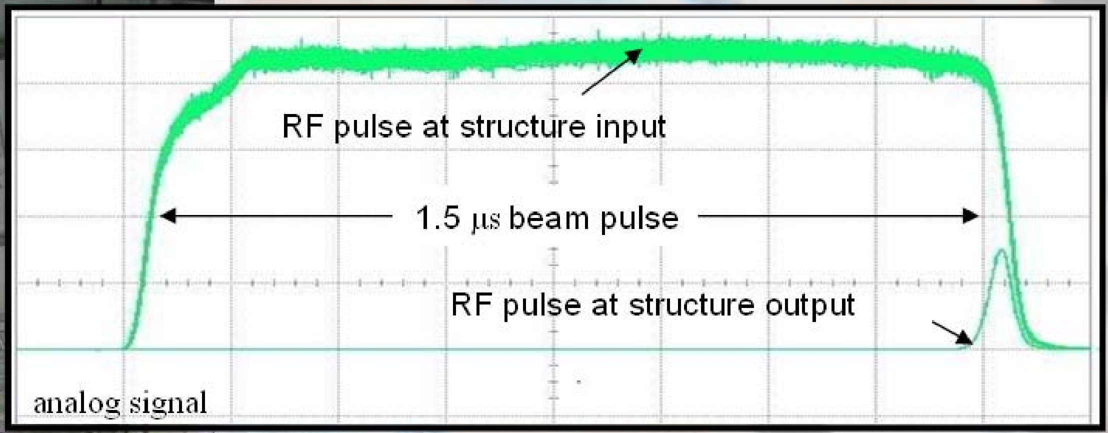
- 3 GHz 2π/3 TW constant aperture
- Slotted-iris damping + detuning with nose cones
- Up to 4 A – 1.4 μs beam pulse accelerated – no sign of BBU

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

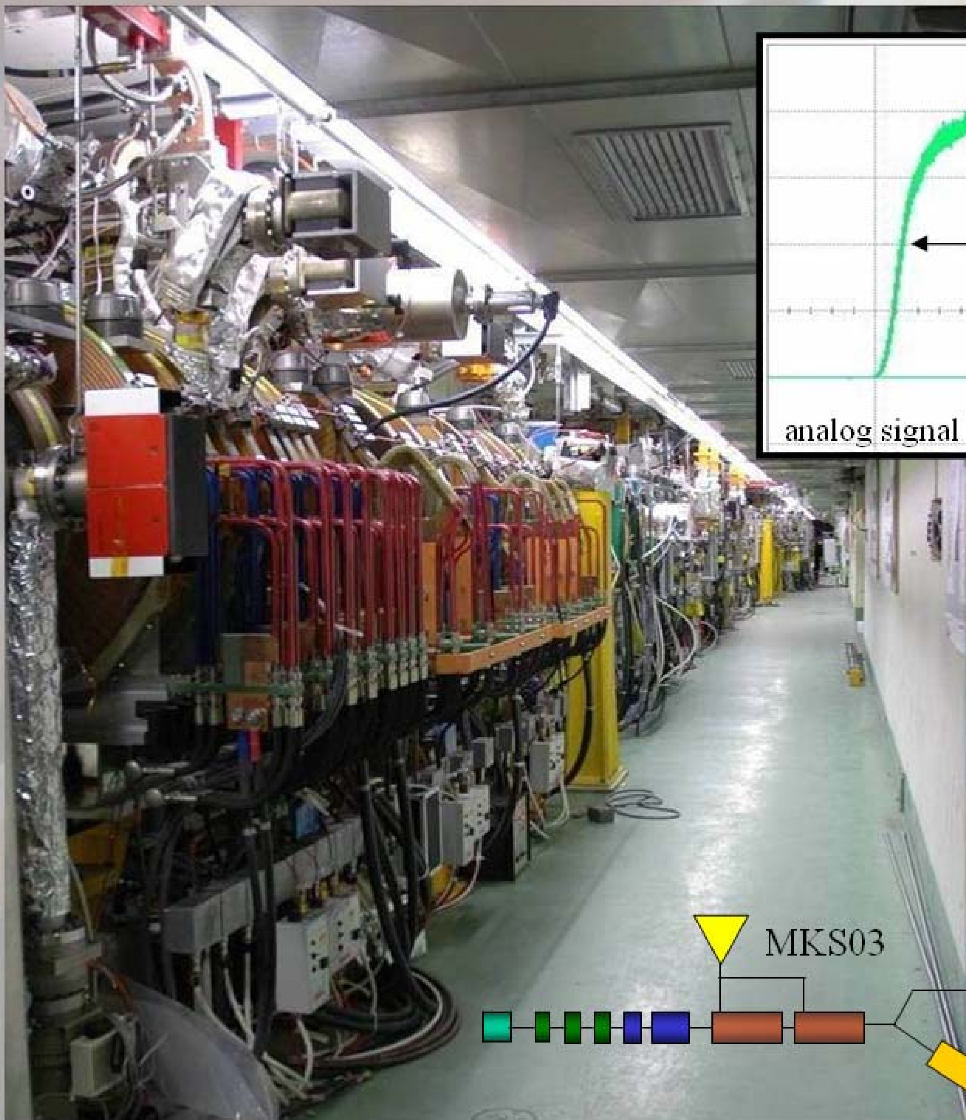
Full beam-loading acceleration in CTF3

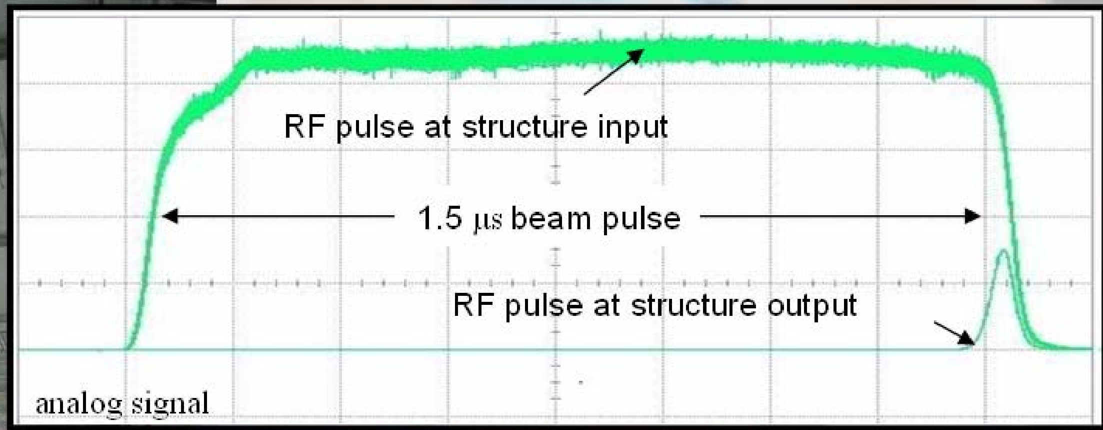
Full beam-loading acceleration in CTF3

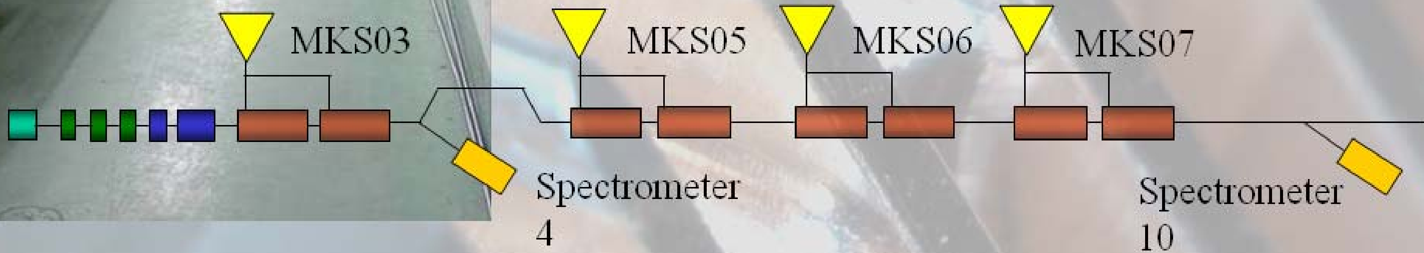




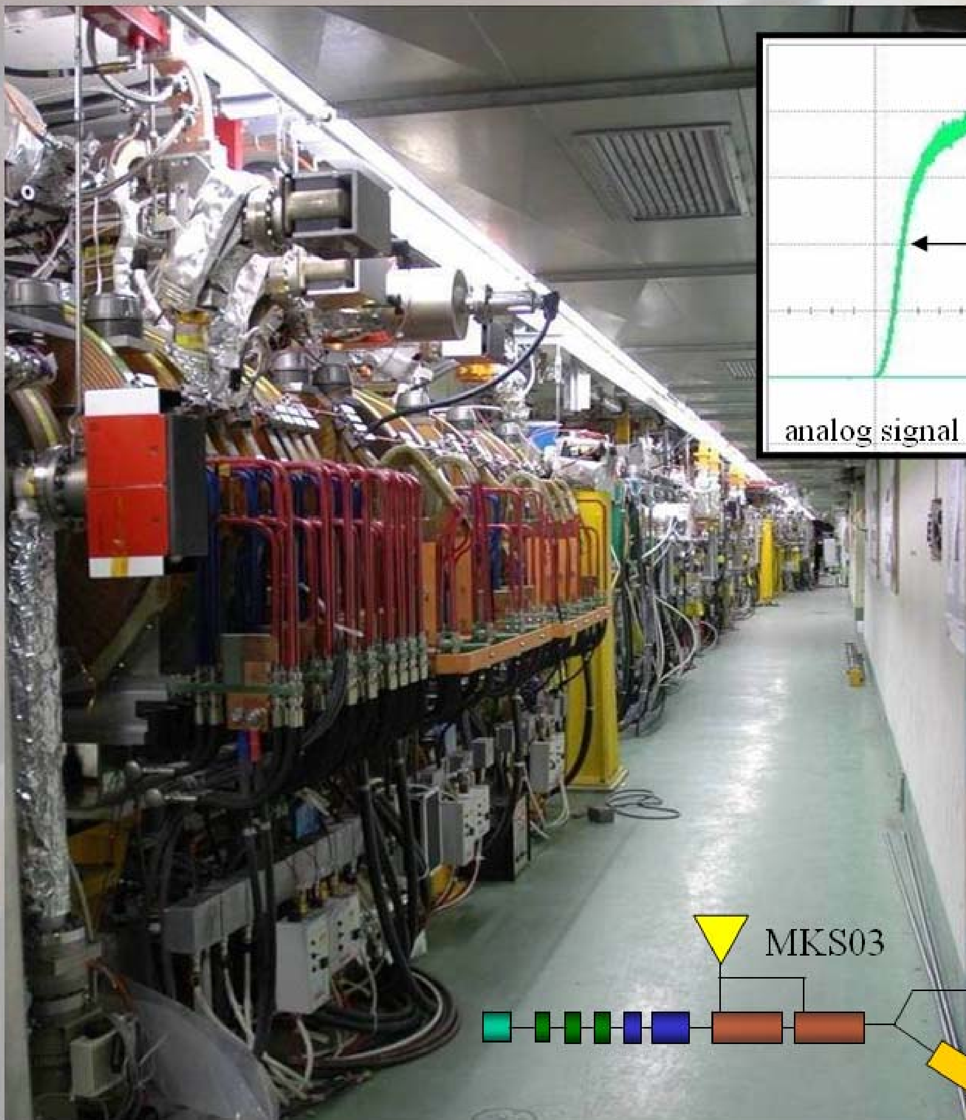
Full beam-loading acceleration in CTF3

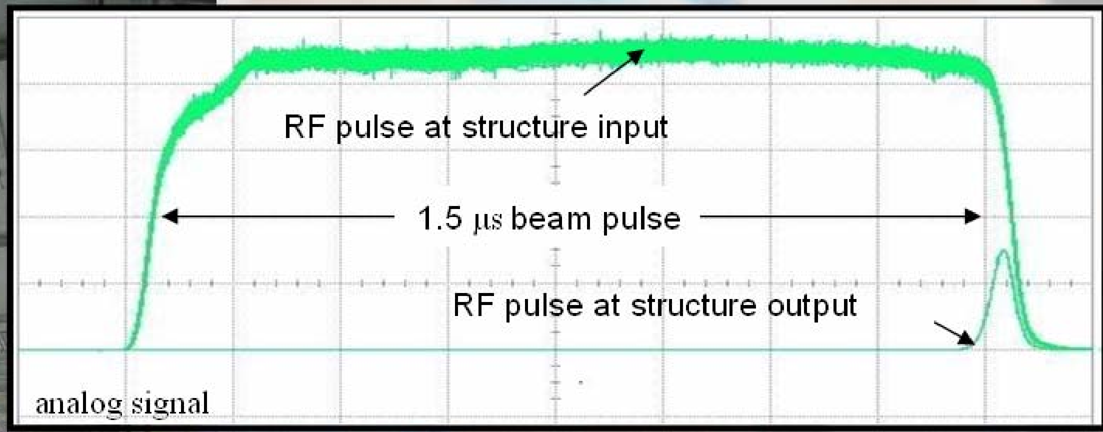






Full beam-loading acceleration in CTF3



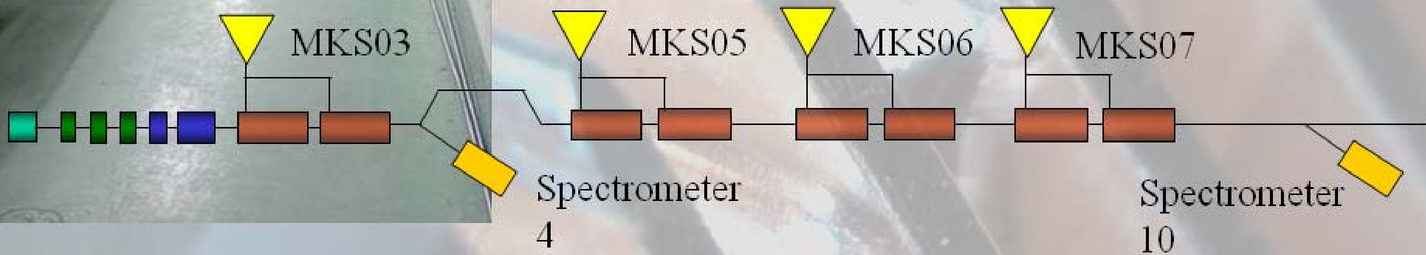


Measured RF-to-beam efficiency

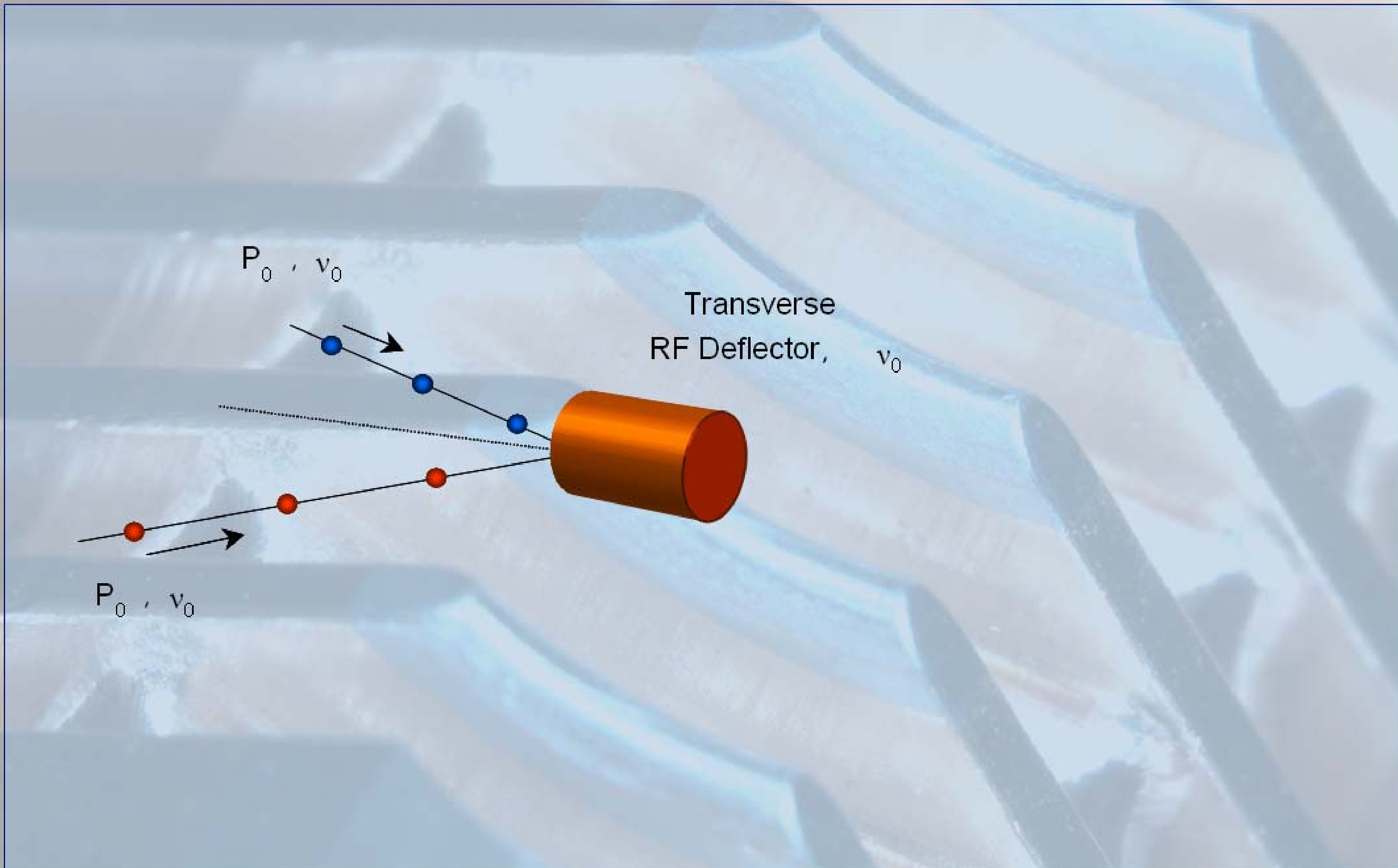
95.3 %

Theory

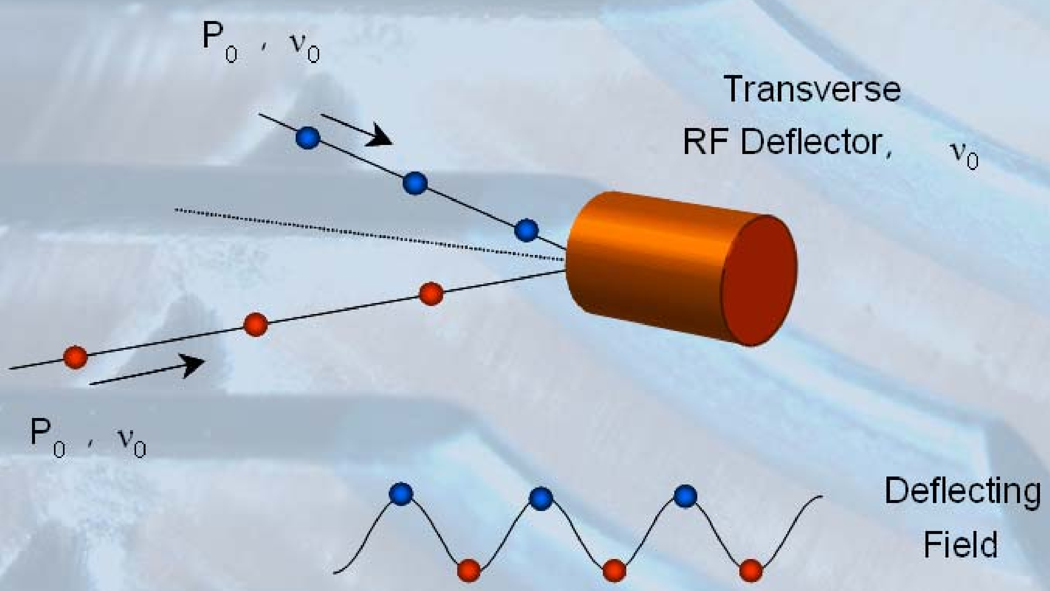
96% (~ 4 % ohmic losses)



Beam combination/separation by transverse RF deflectors



Beam combination/separation by transverse RF deflectors



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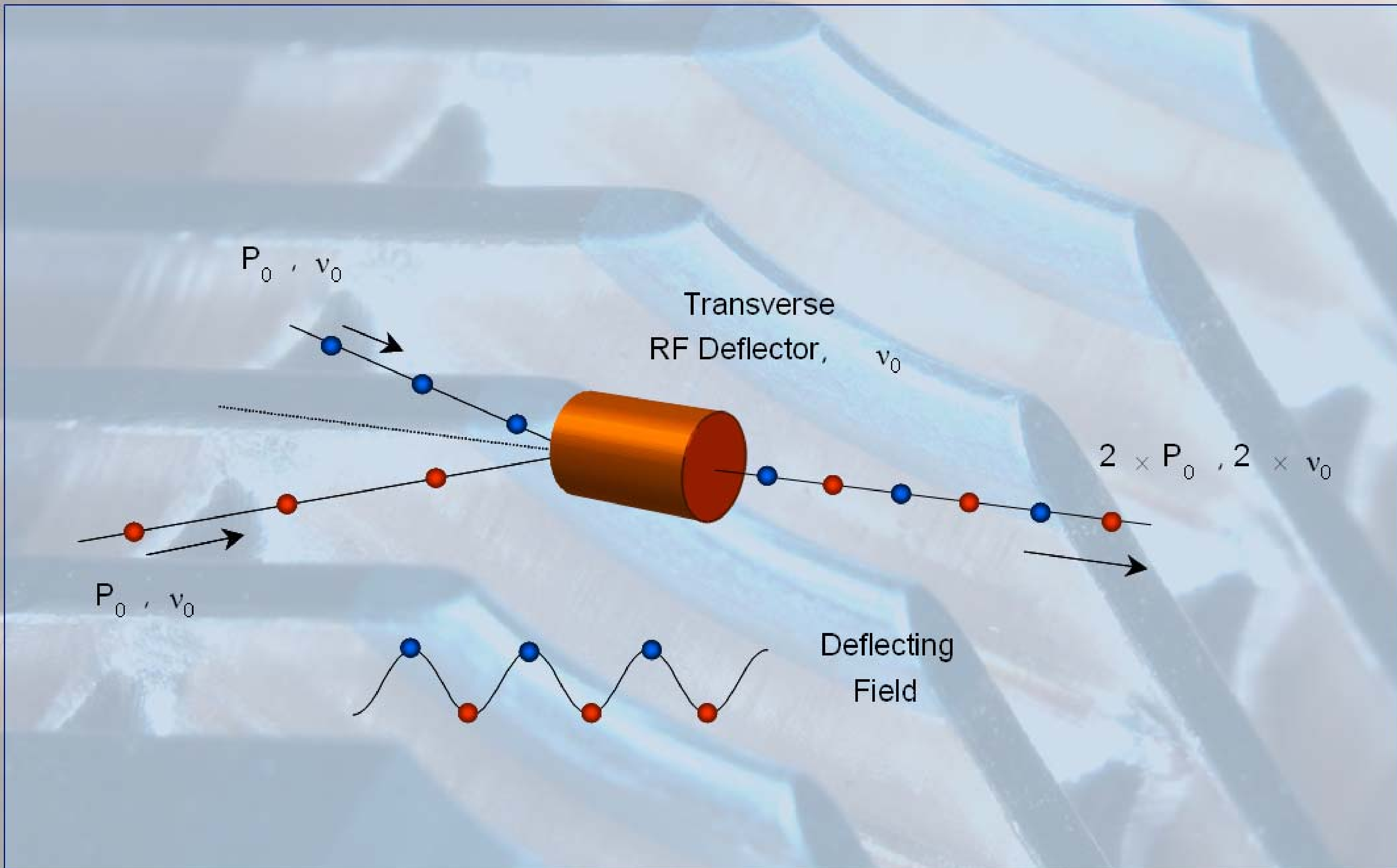
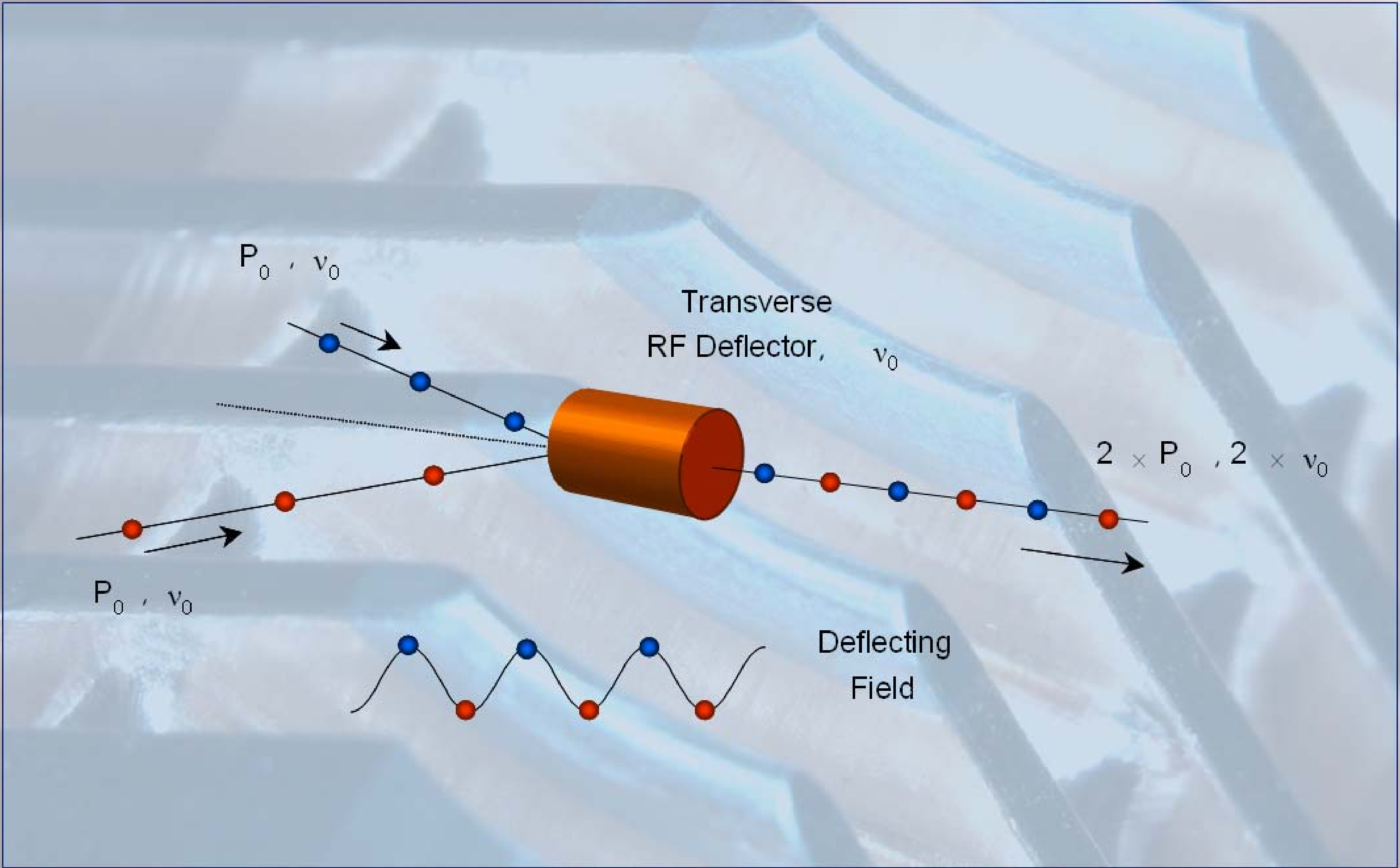
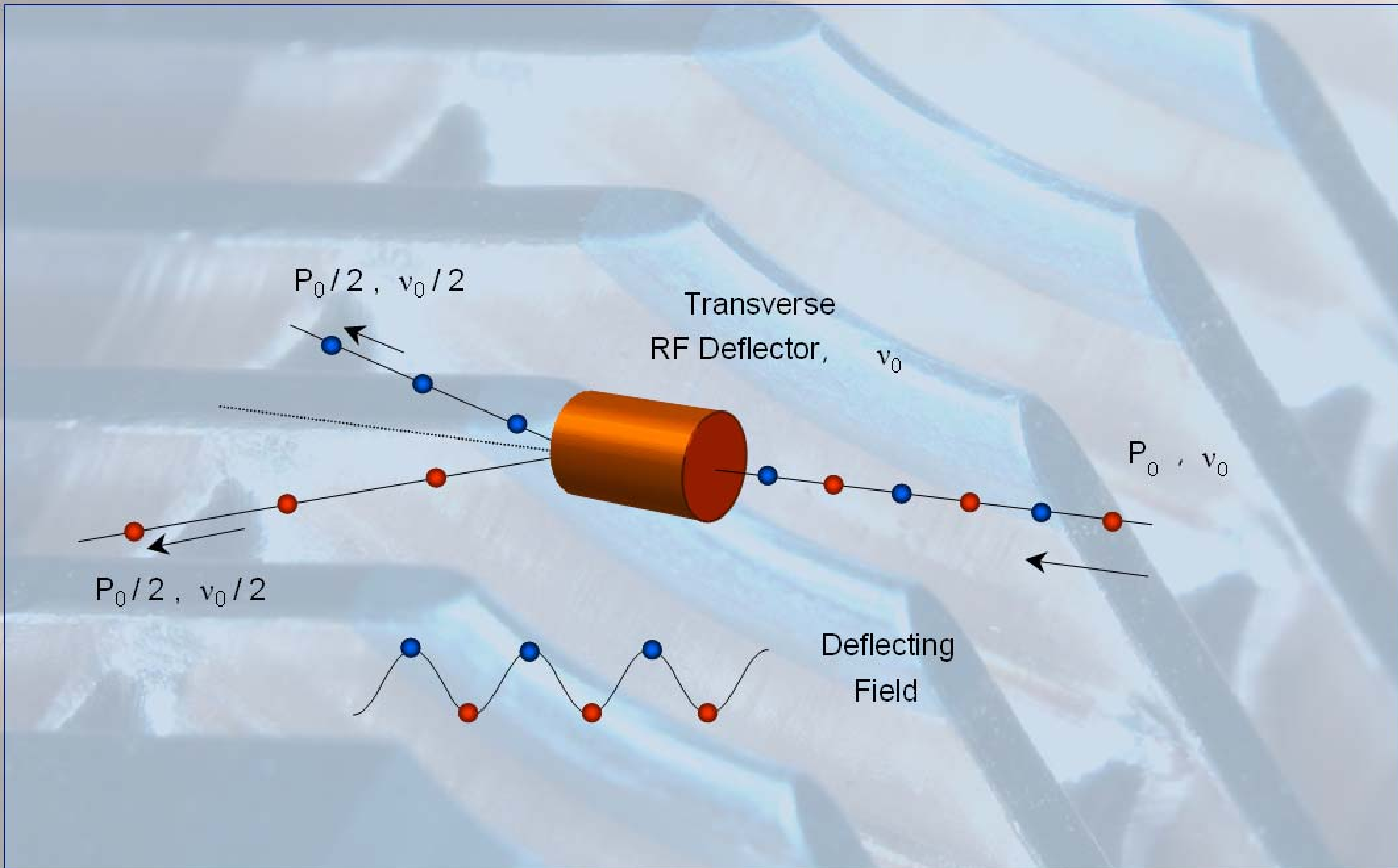


Beam combination/separation by transverse RF deflectors

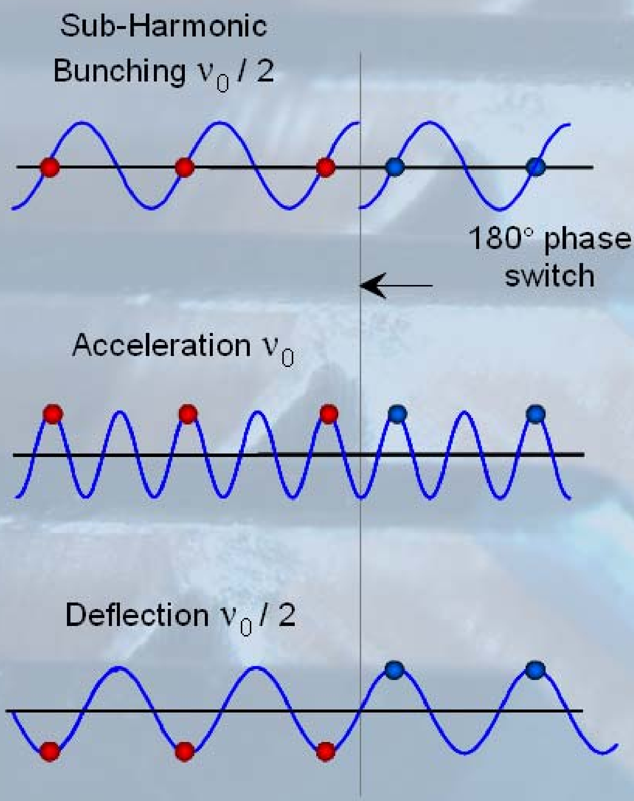


Beam combination/separation by transverse RF deflectors



Phase coding

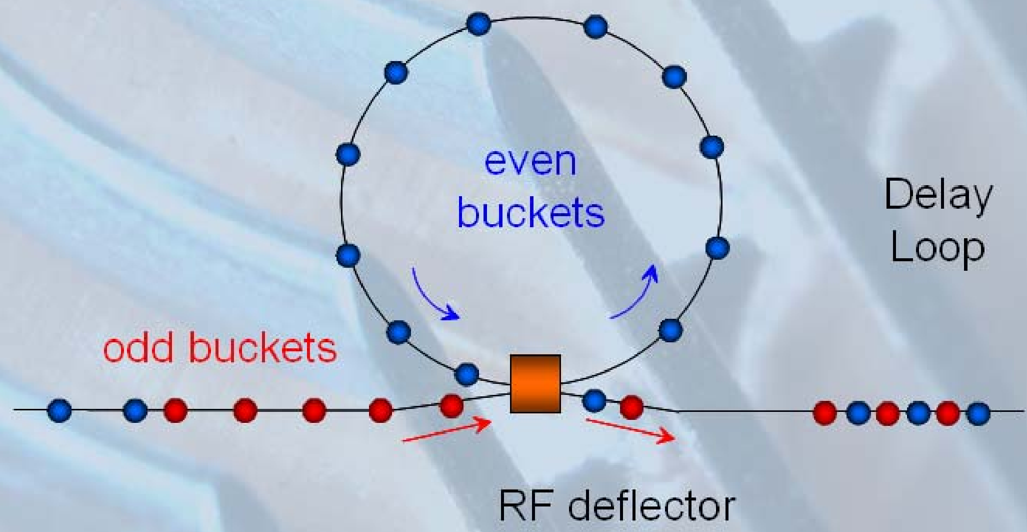
How to "code" the sub-pulses



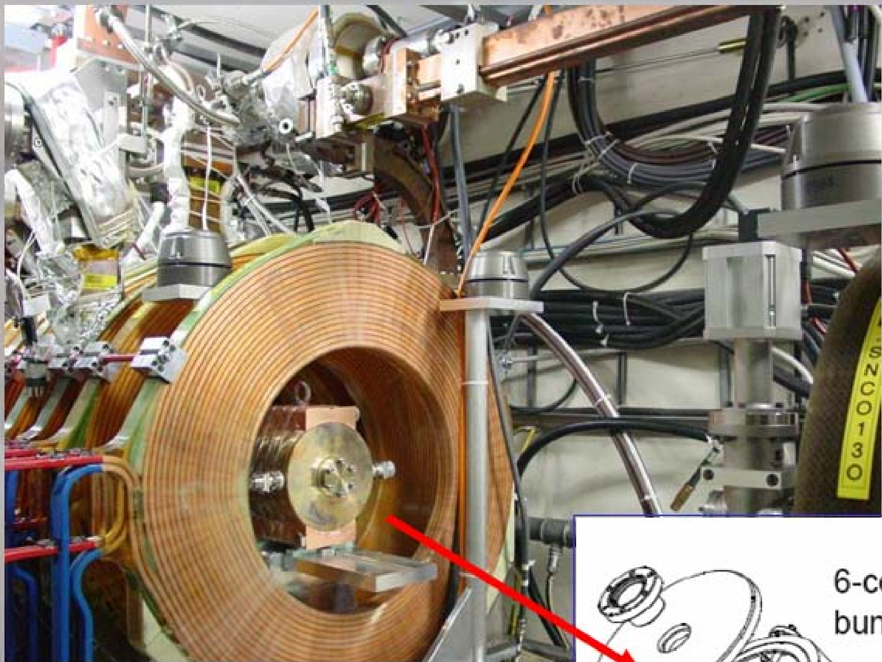
Gap creation & first multiplication × 2

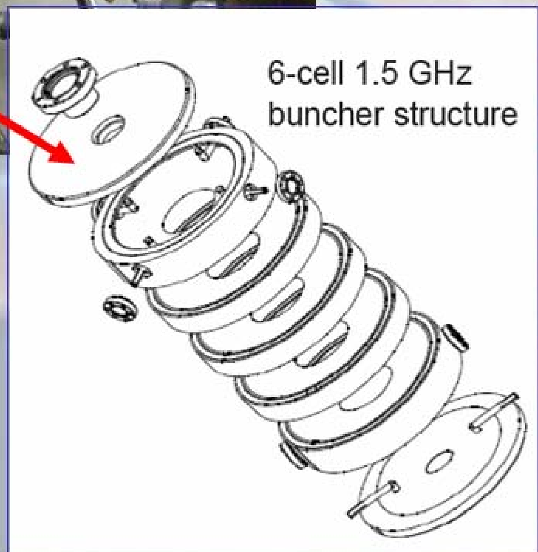
$$L_{delay} = n\,\lambda_0 = c\,T_{sub\text{-}pulse}$$

Combination scheme



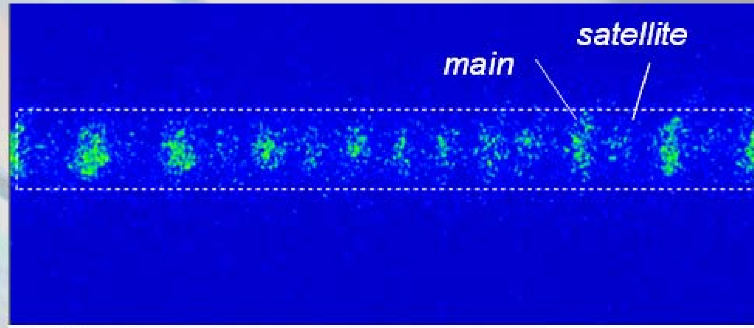
Fast phase switch from SHB system (CTF3)

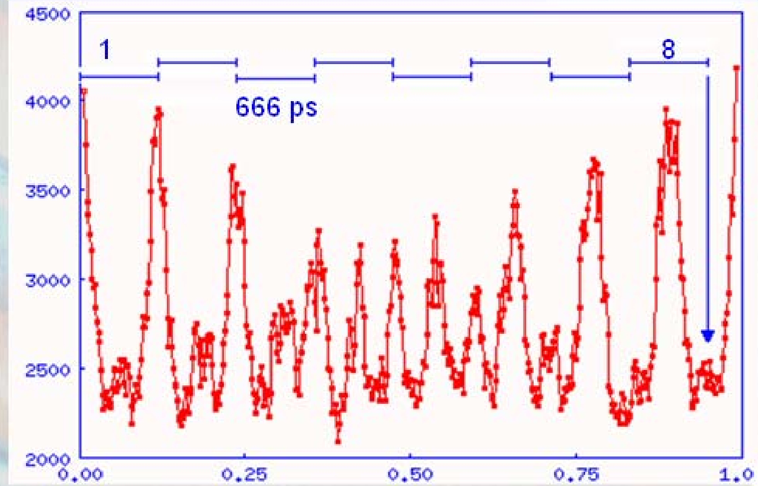




3 TW Sub-harmonic bunchers, each fed by a wide-band TWT

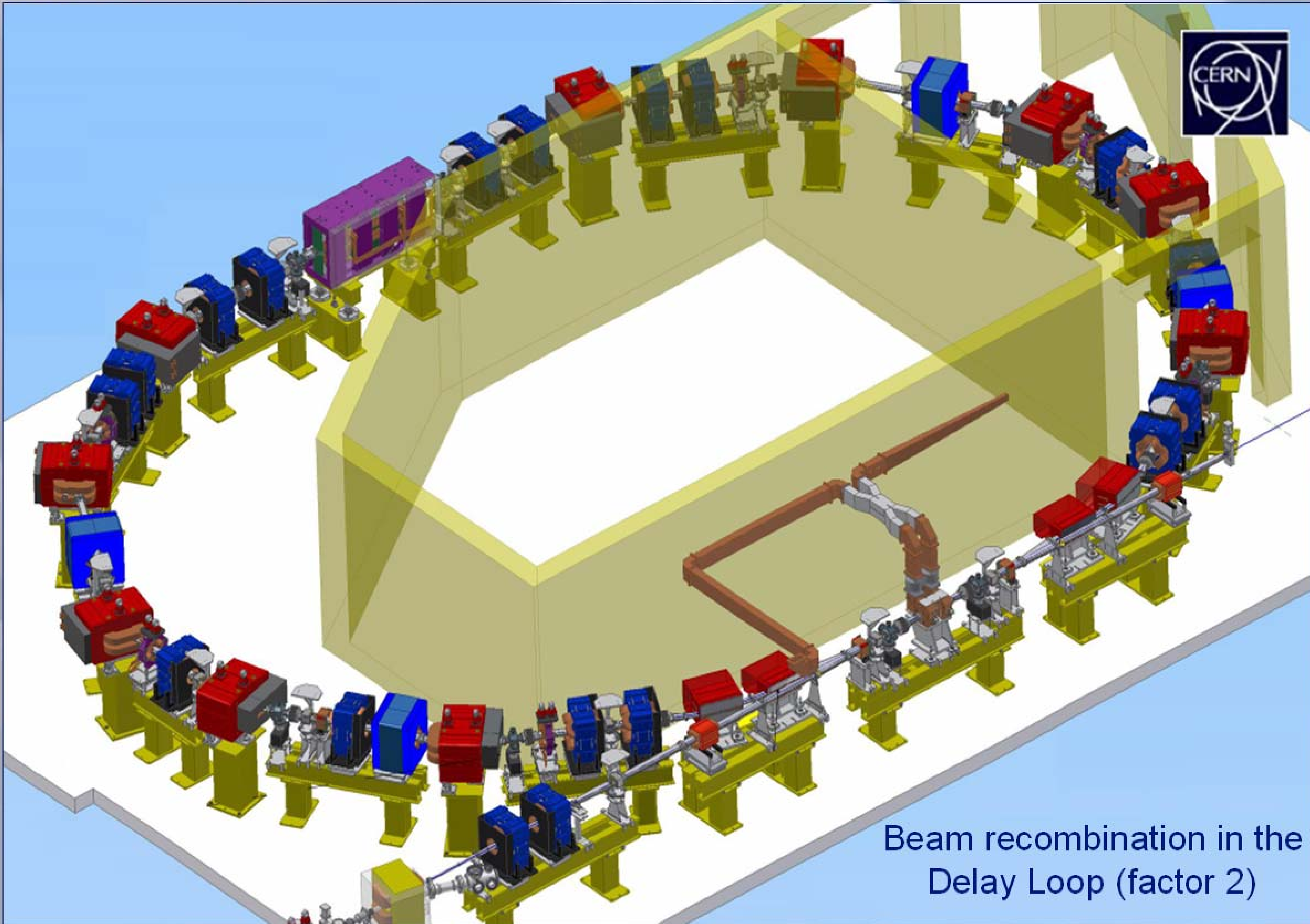
Streak camera image





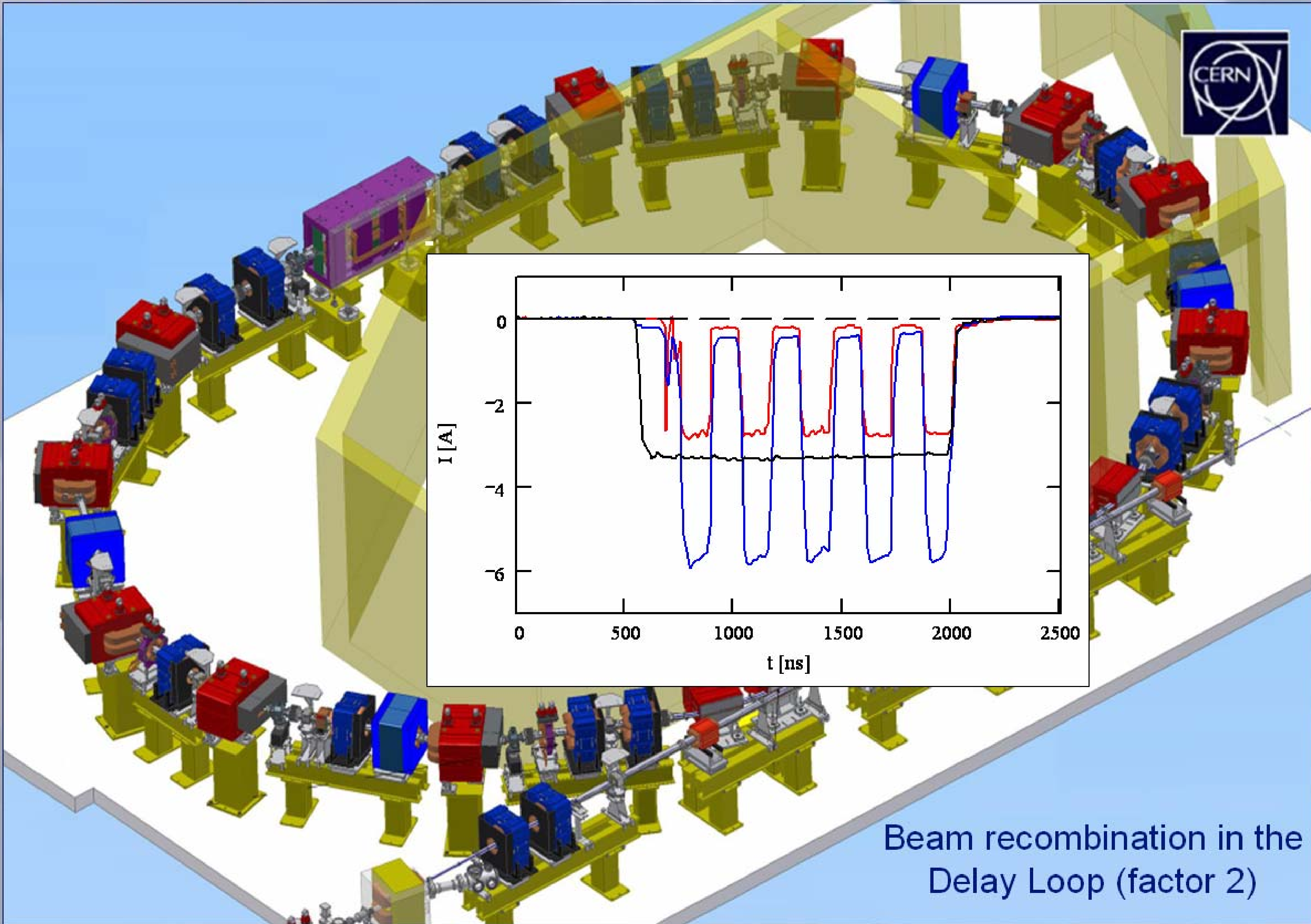
$8.5 \cdot 666$ ps = 5.7 ns

Results from CLIC proof of principle in CTF3



Beam recombination in the Delay Loop (factor 2)

Results from CLIC proof of principle in CTF3



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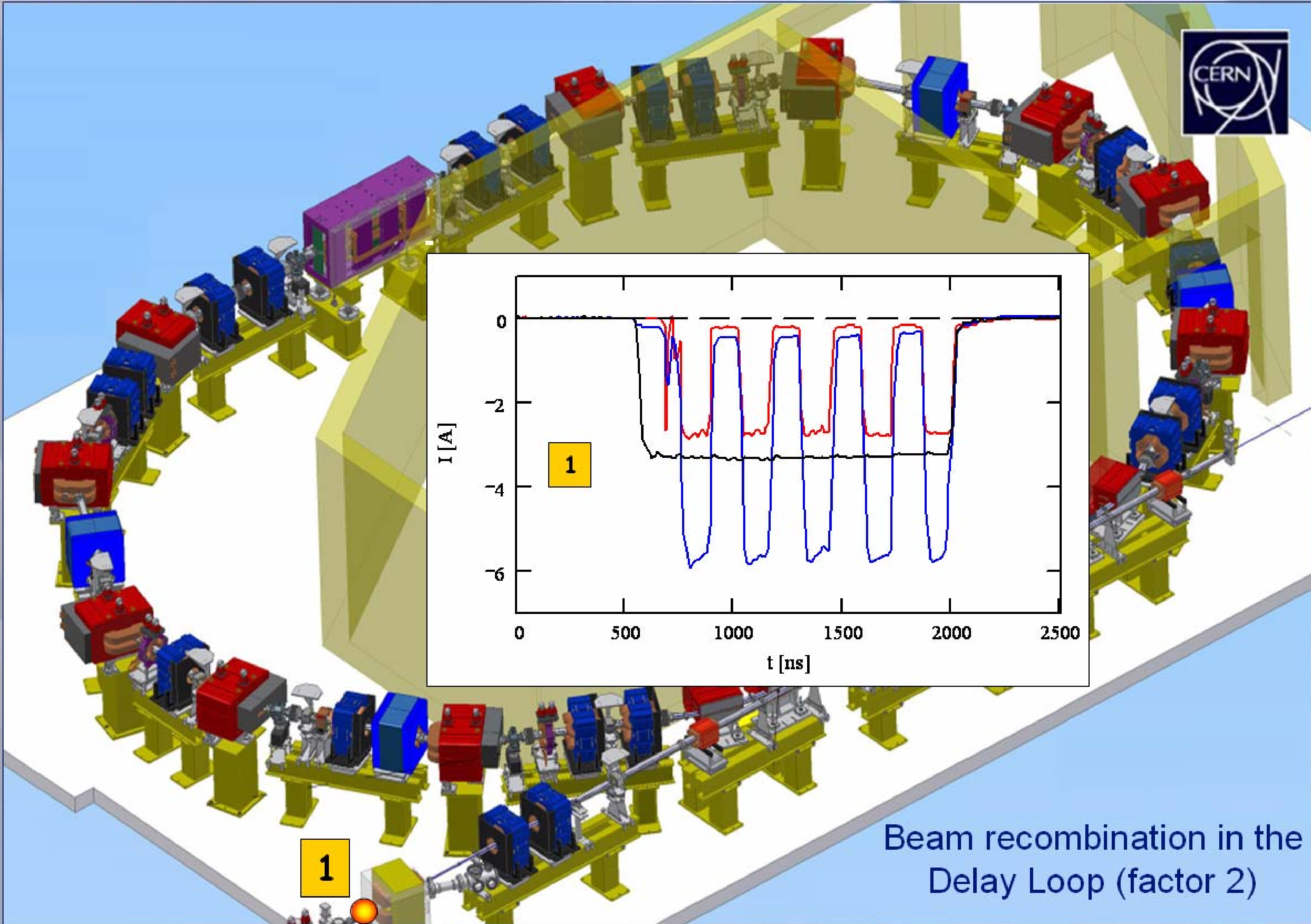

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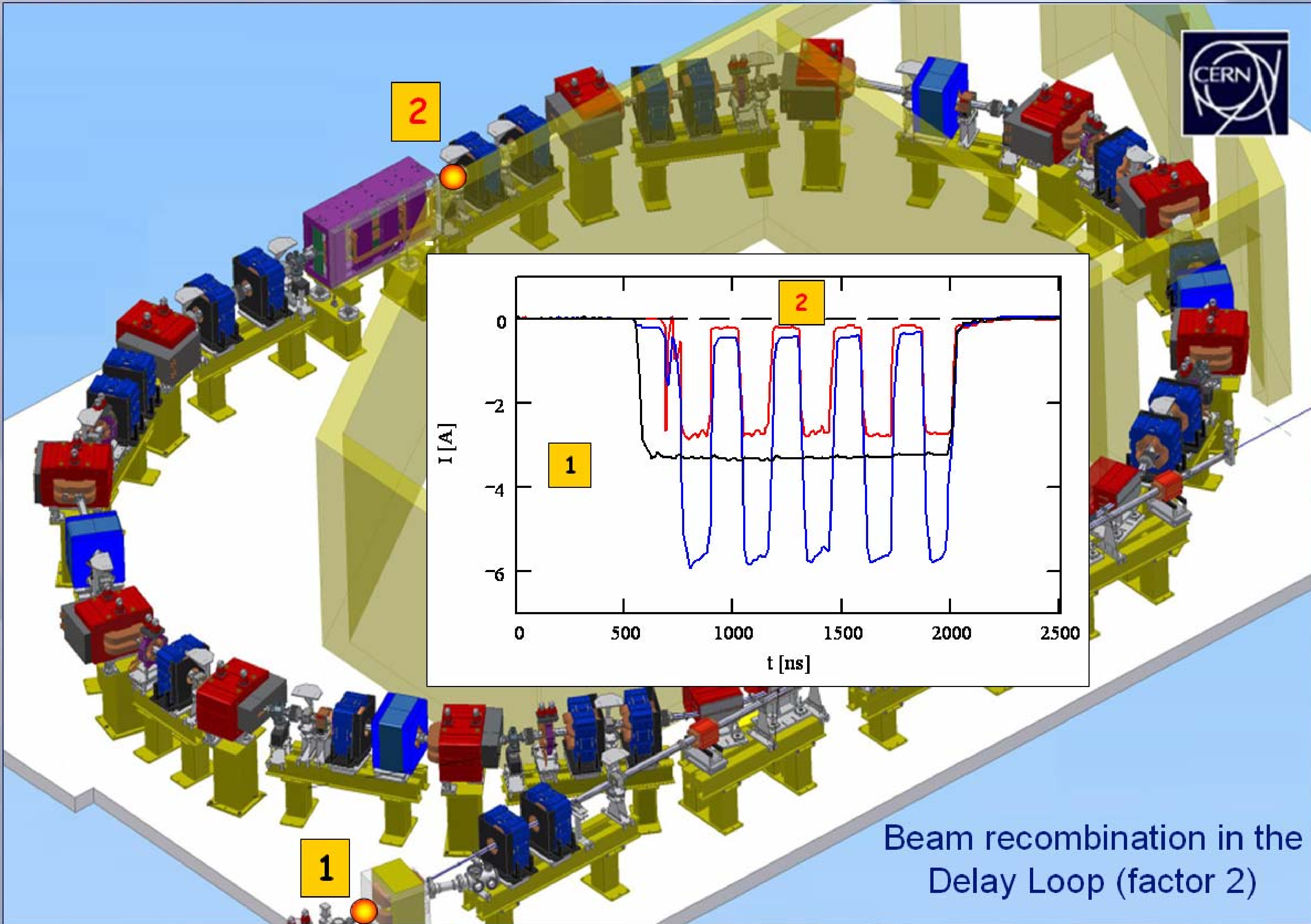

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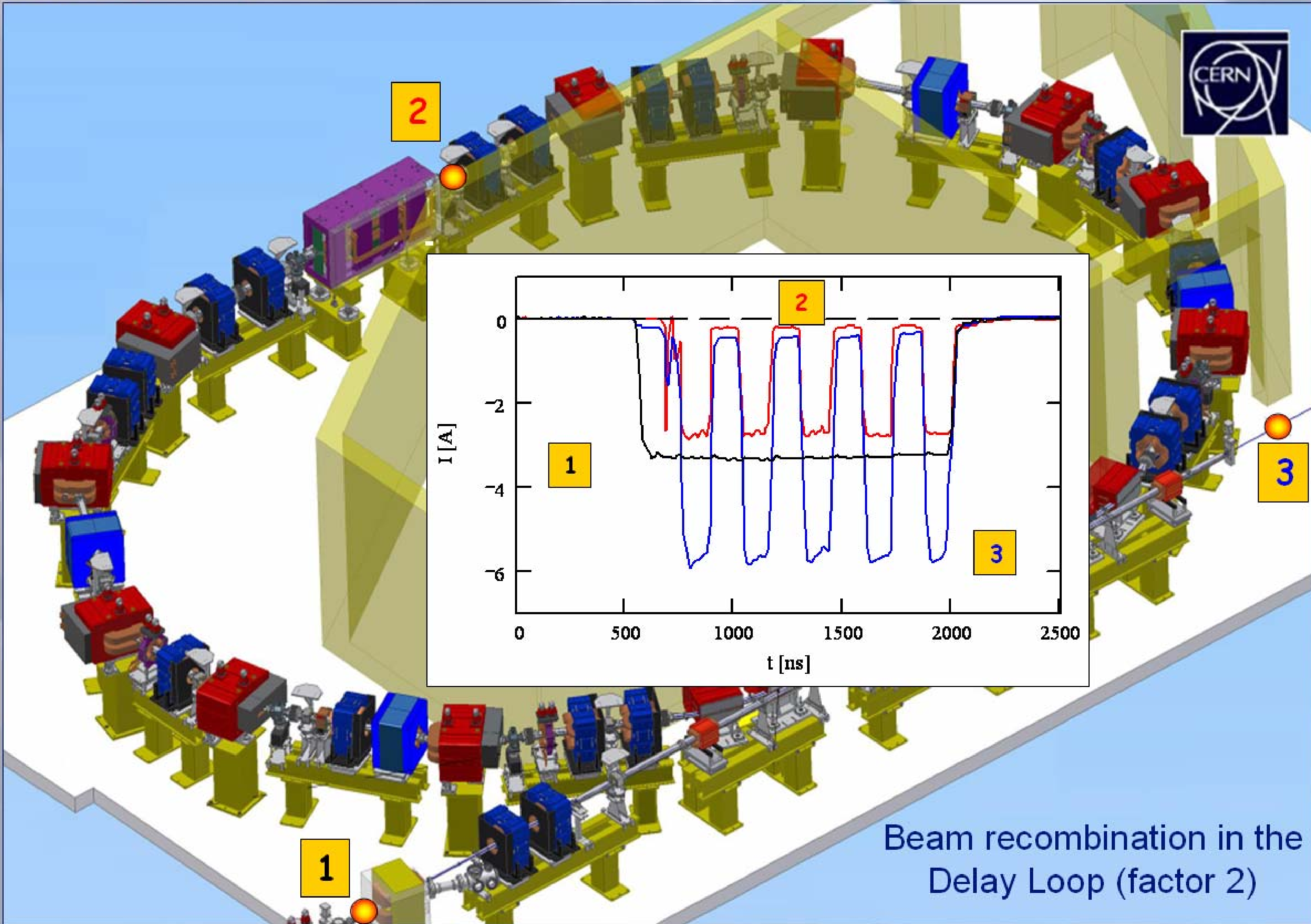

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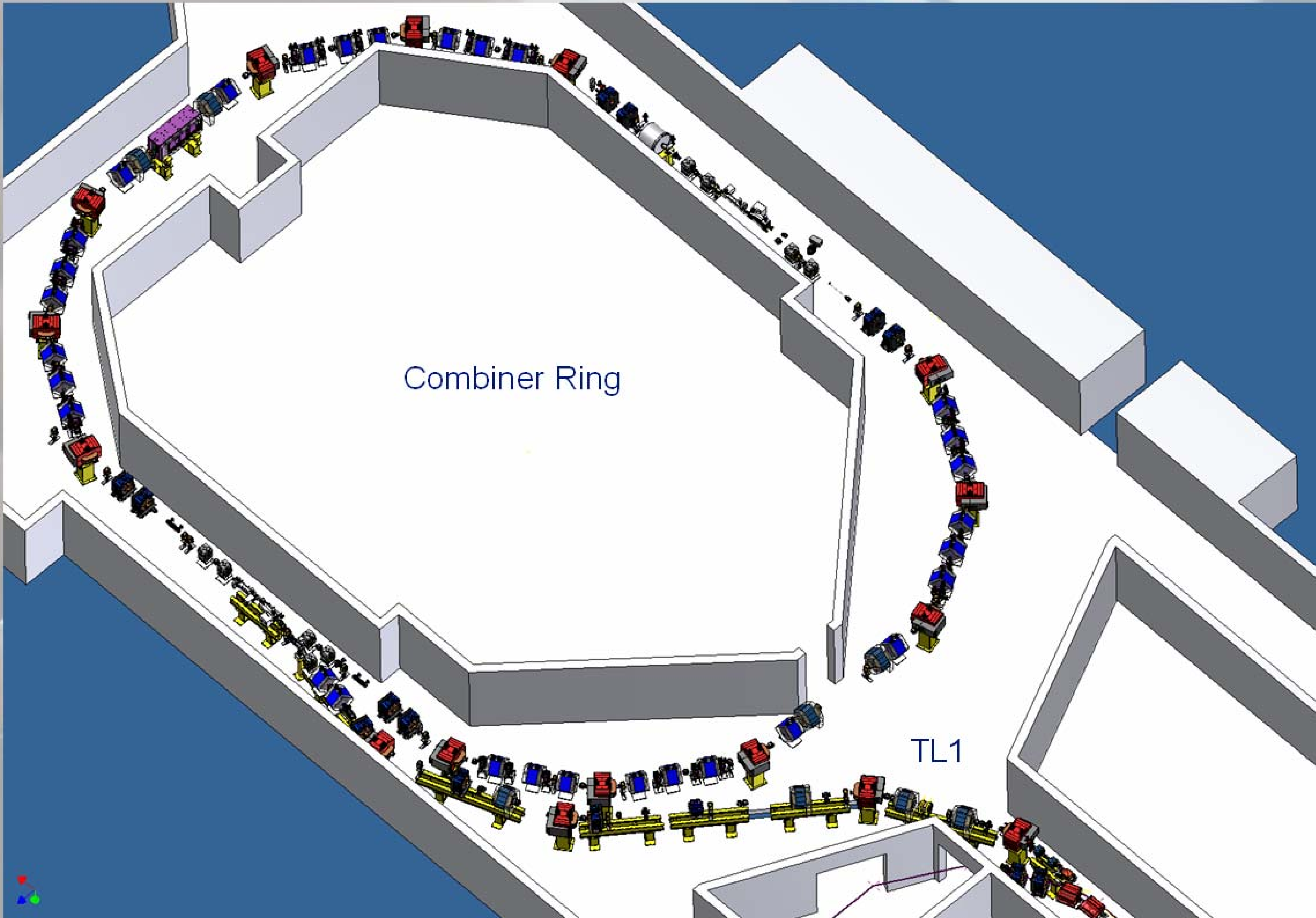

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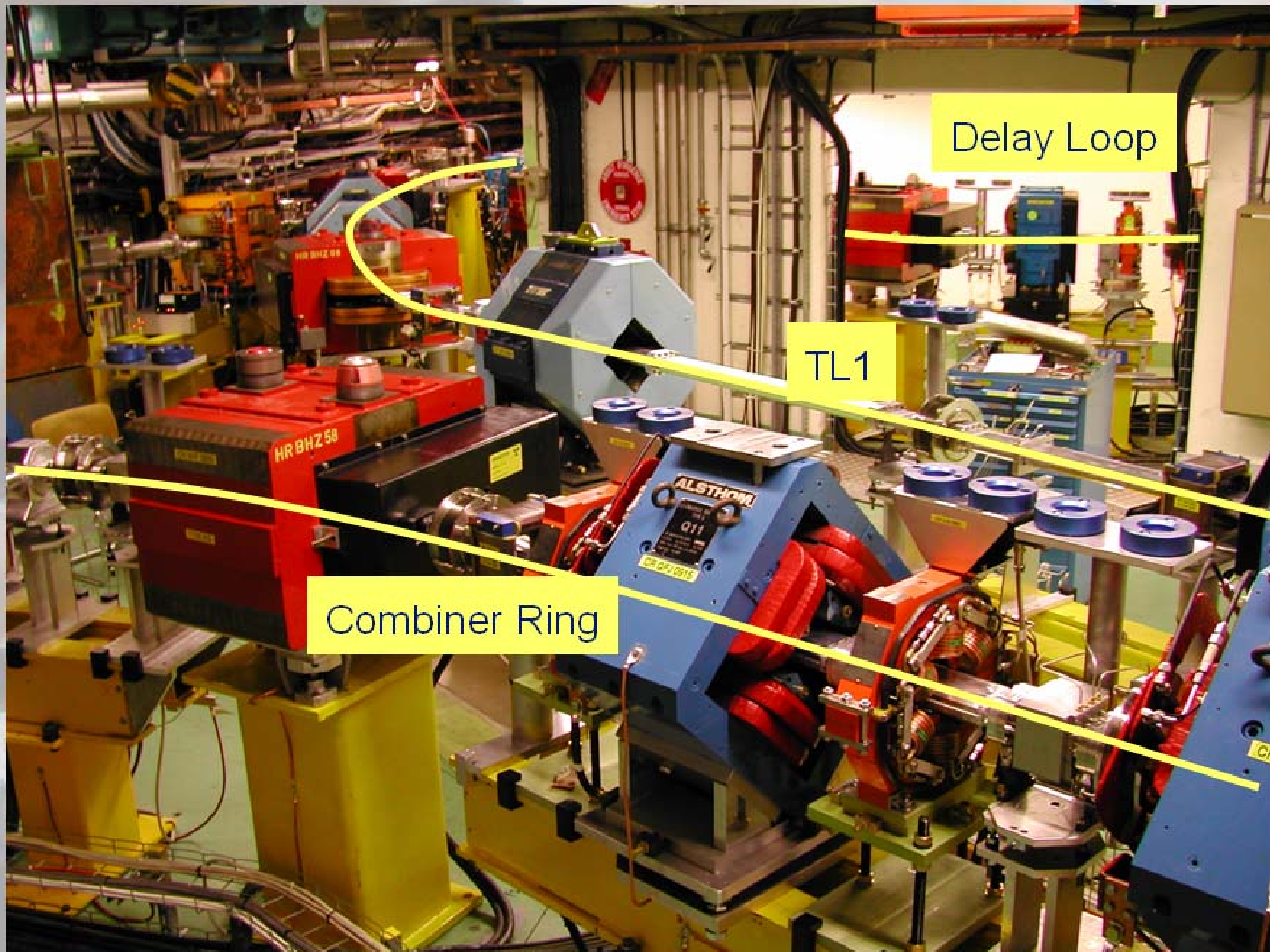
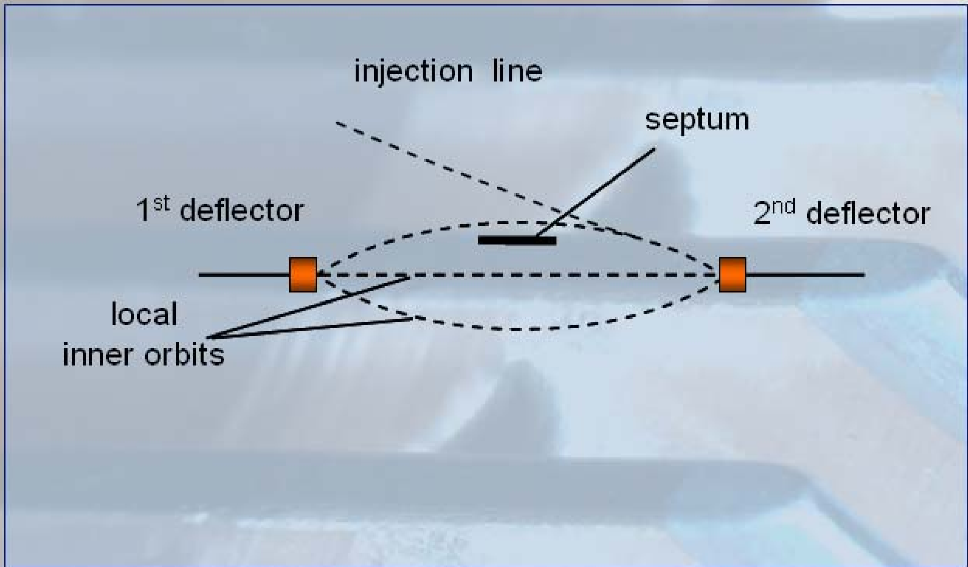
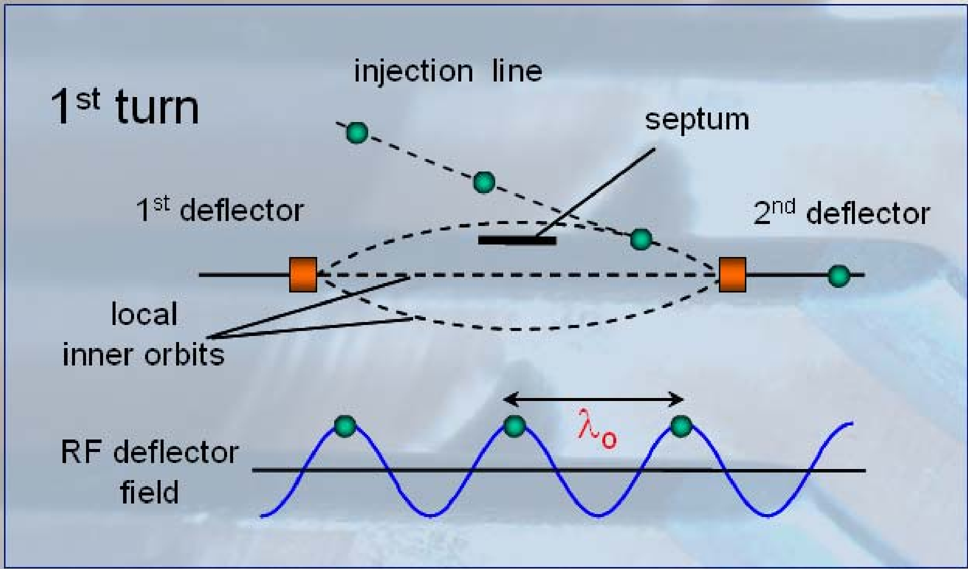


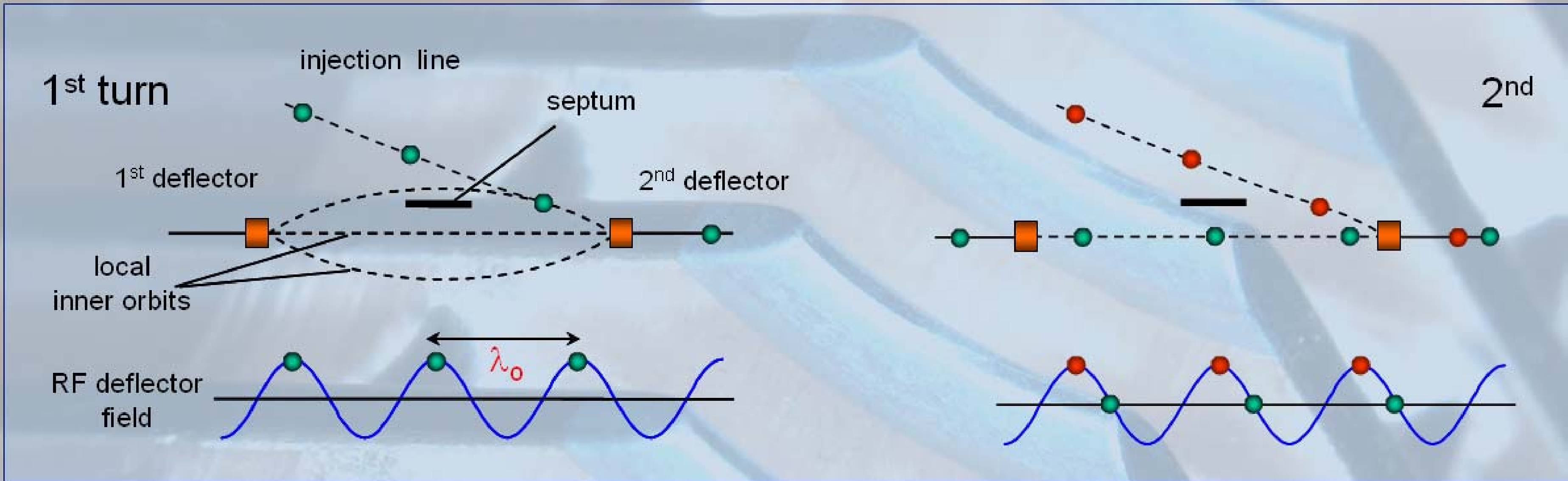
RF injection in combiner ring



RF injection in combiner ring

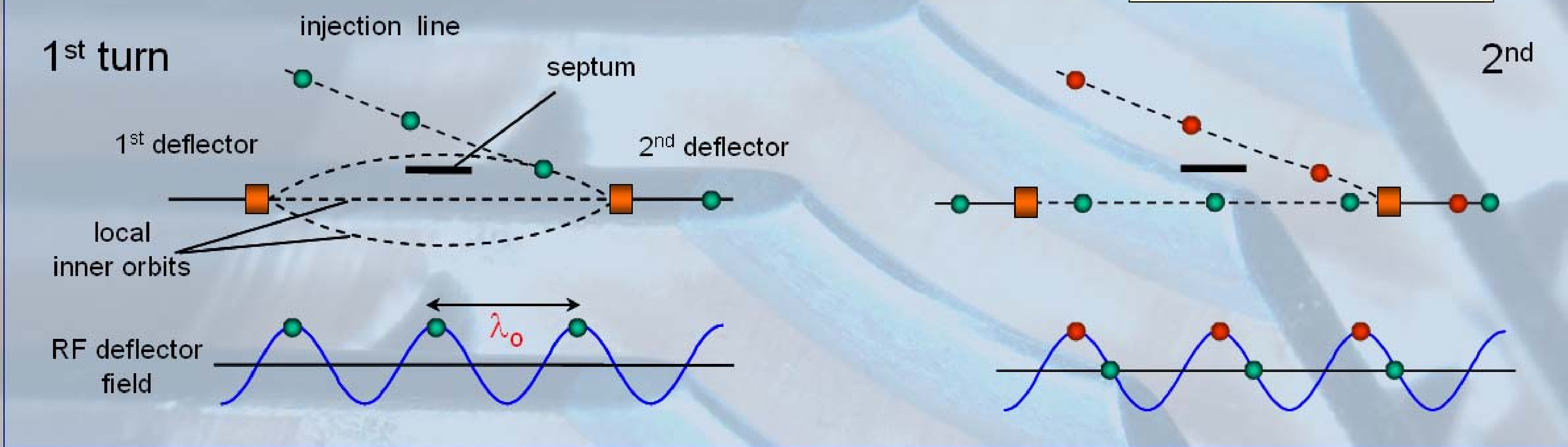


RF injection in combiner ring



RF injection in combiner ring

$$C_{ring} = (n + 1/4)\,\lambda$$



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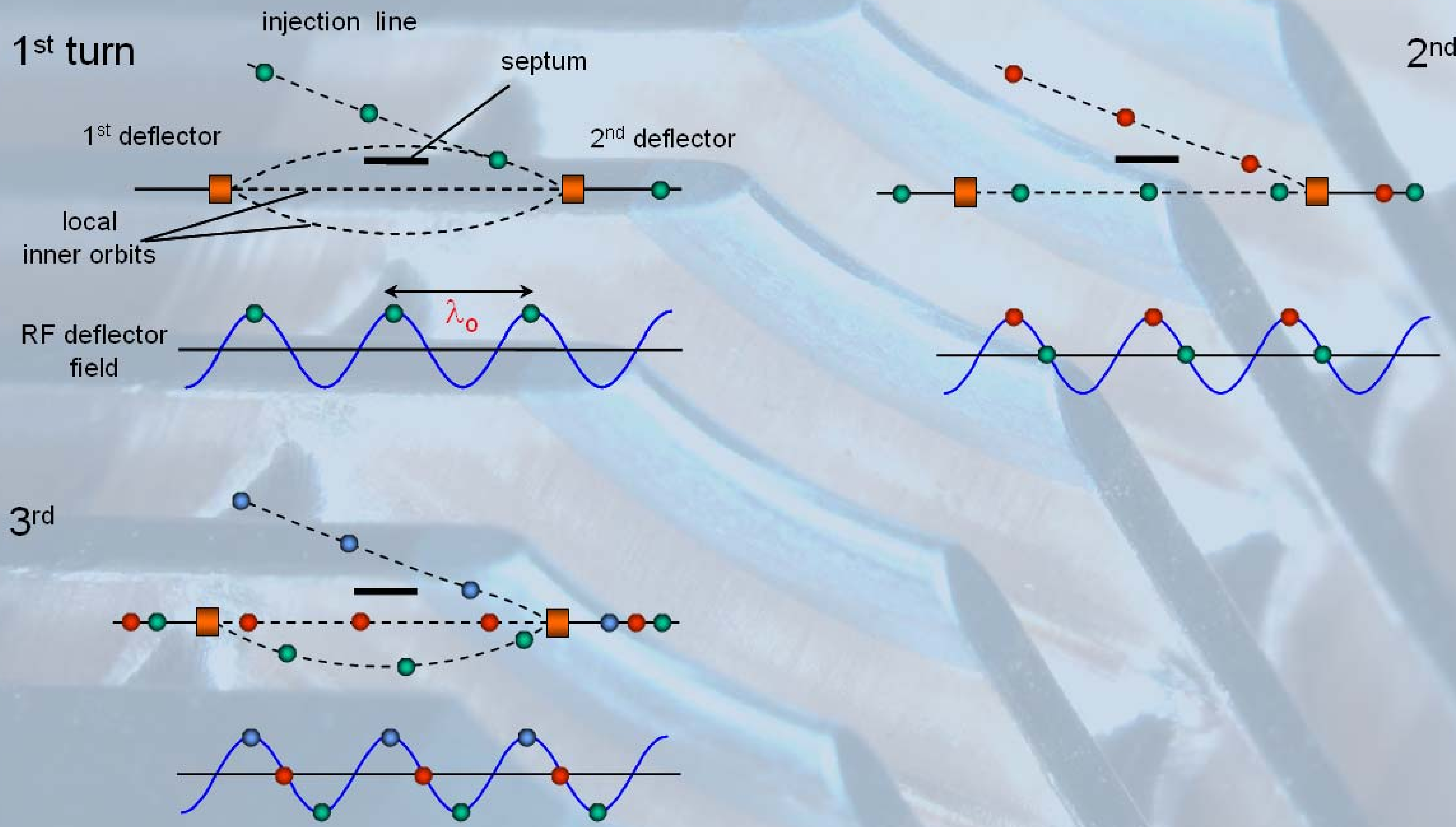

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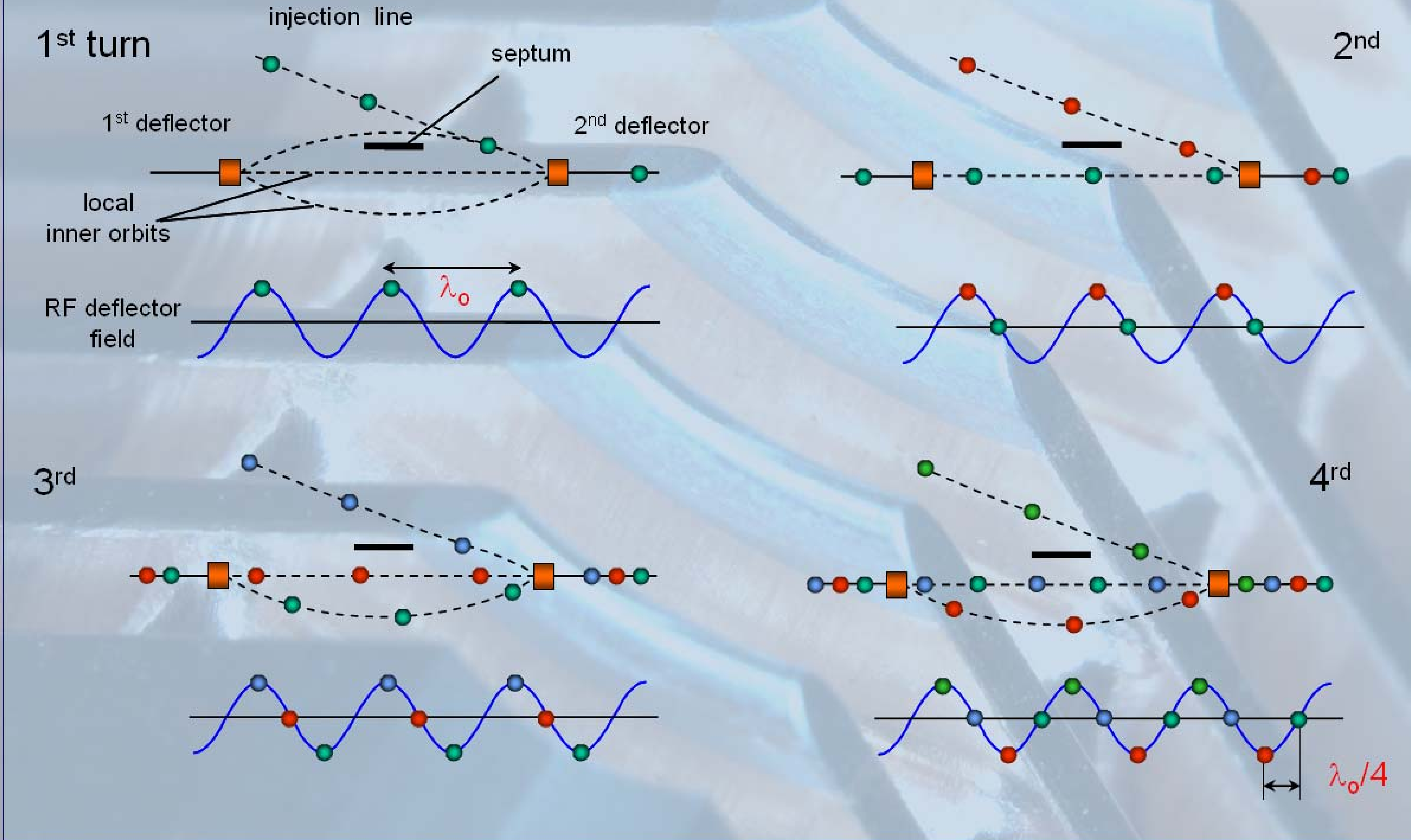
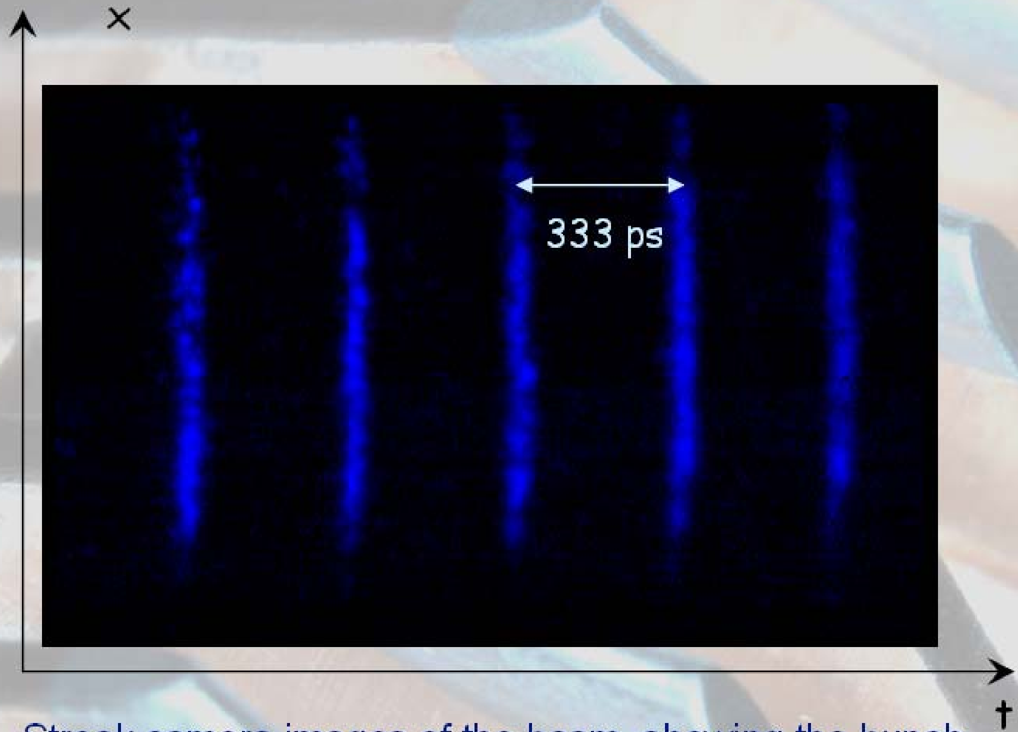


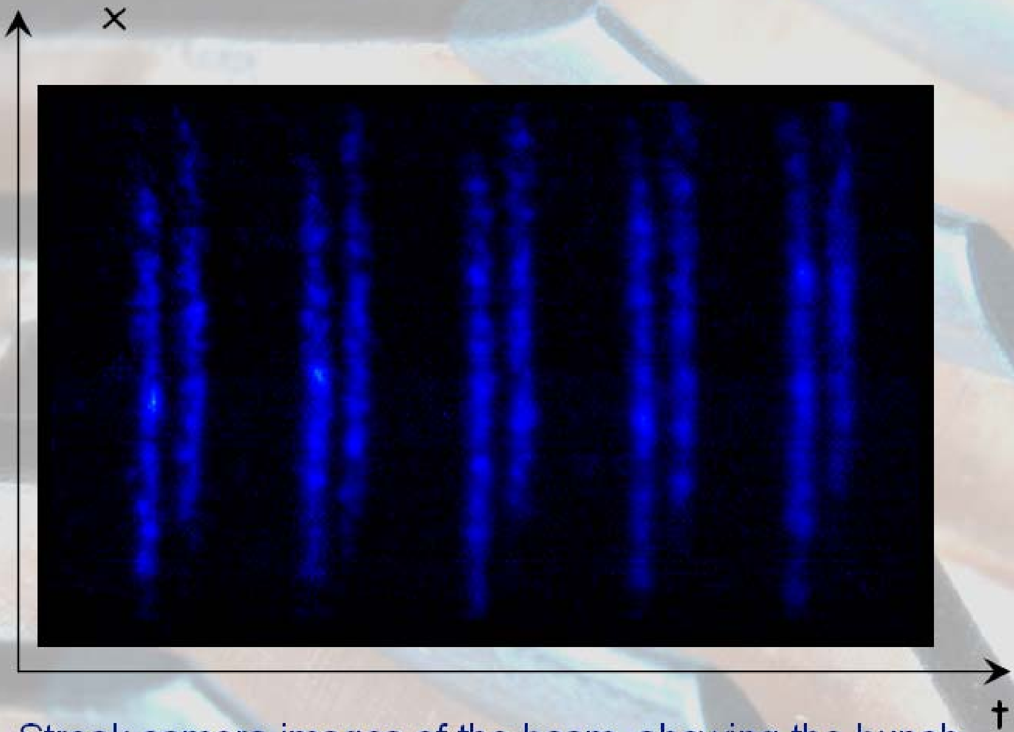
RF injection in combiner ring in CTF3 preliminary phase (2001-2002)



Streak camera images of the beam, showing the bunch combination process

A first ring combination test was performed in 2002, *at low current and short pulse*, in the CERN Electron-Positron Accumulator (EPA), properly modified

RF injection in combiner ring in CTF3 preliminary phase (2001-2002)



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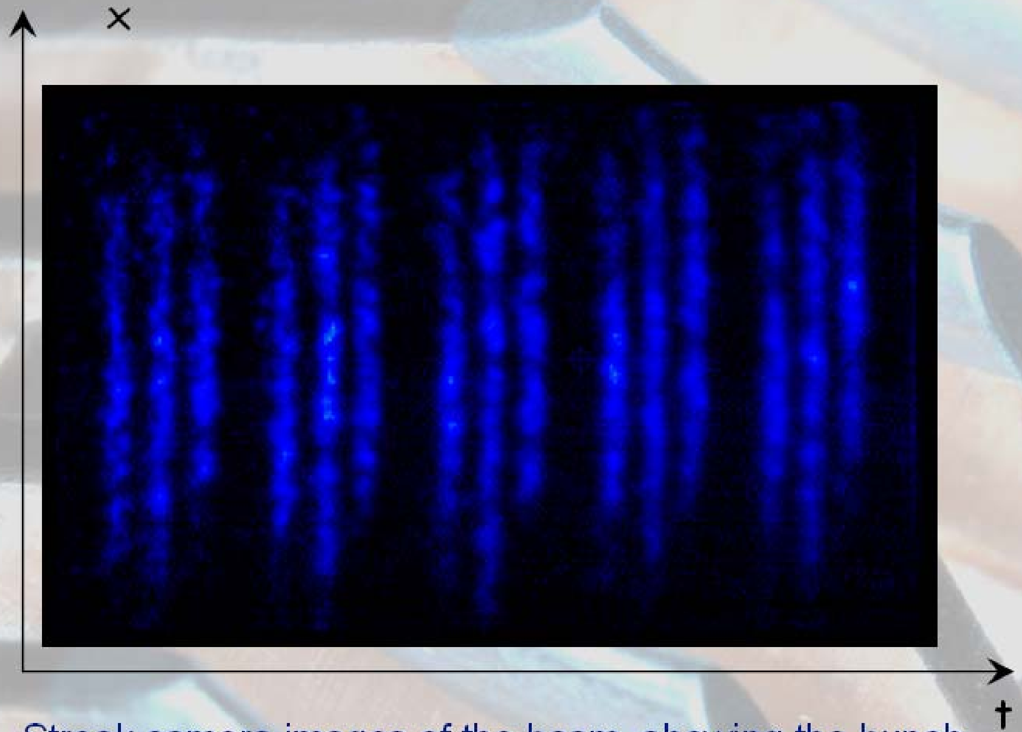

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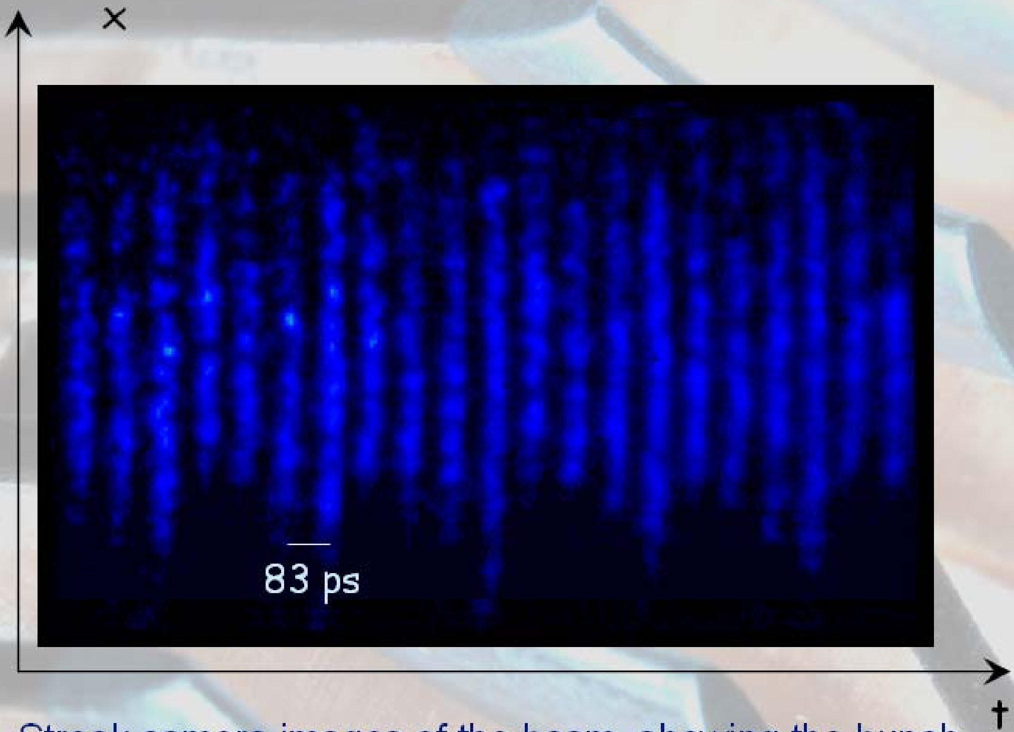

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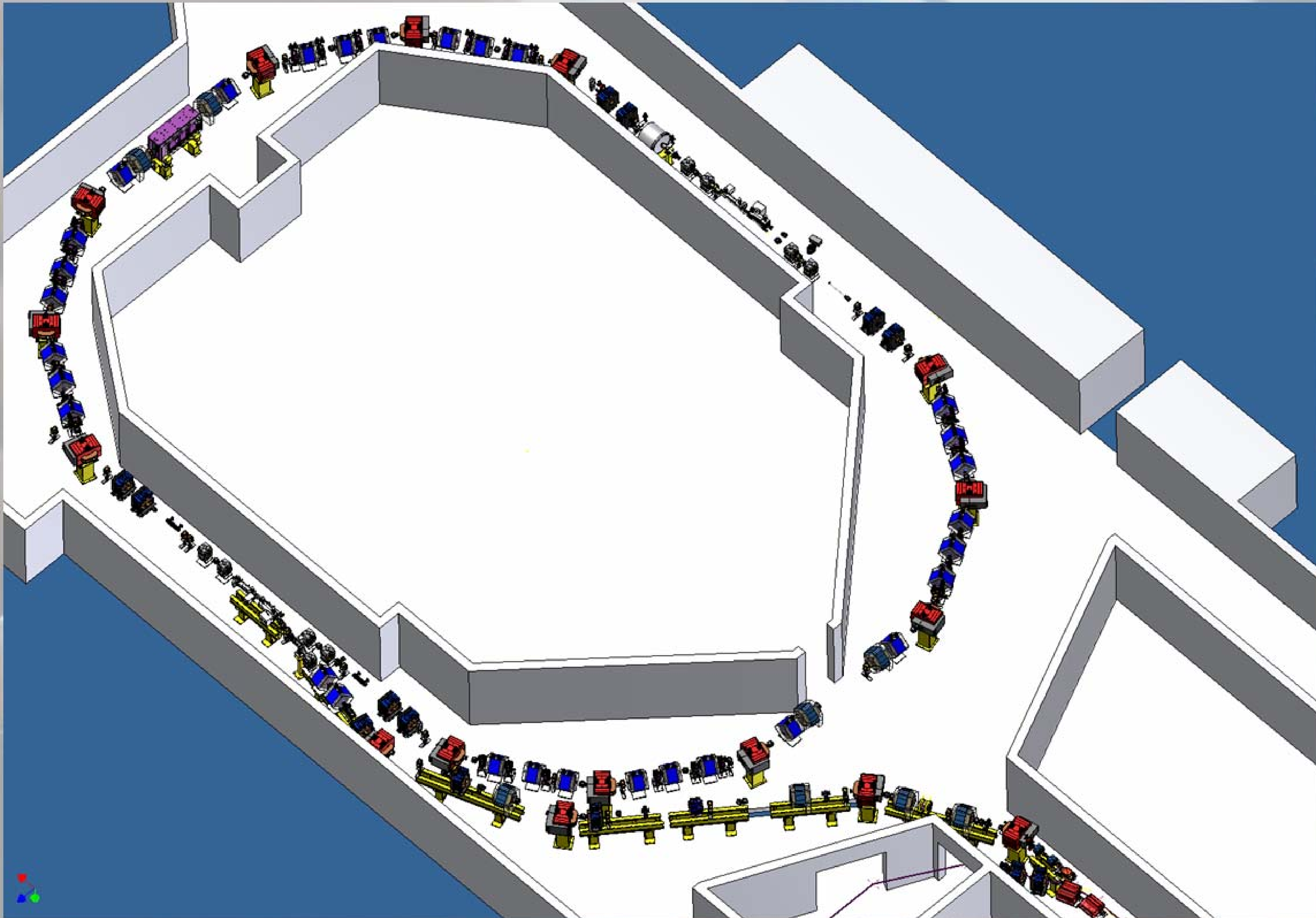
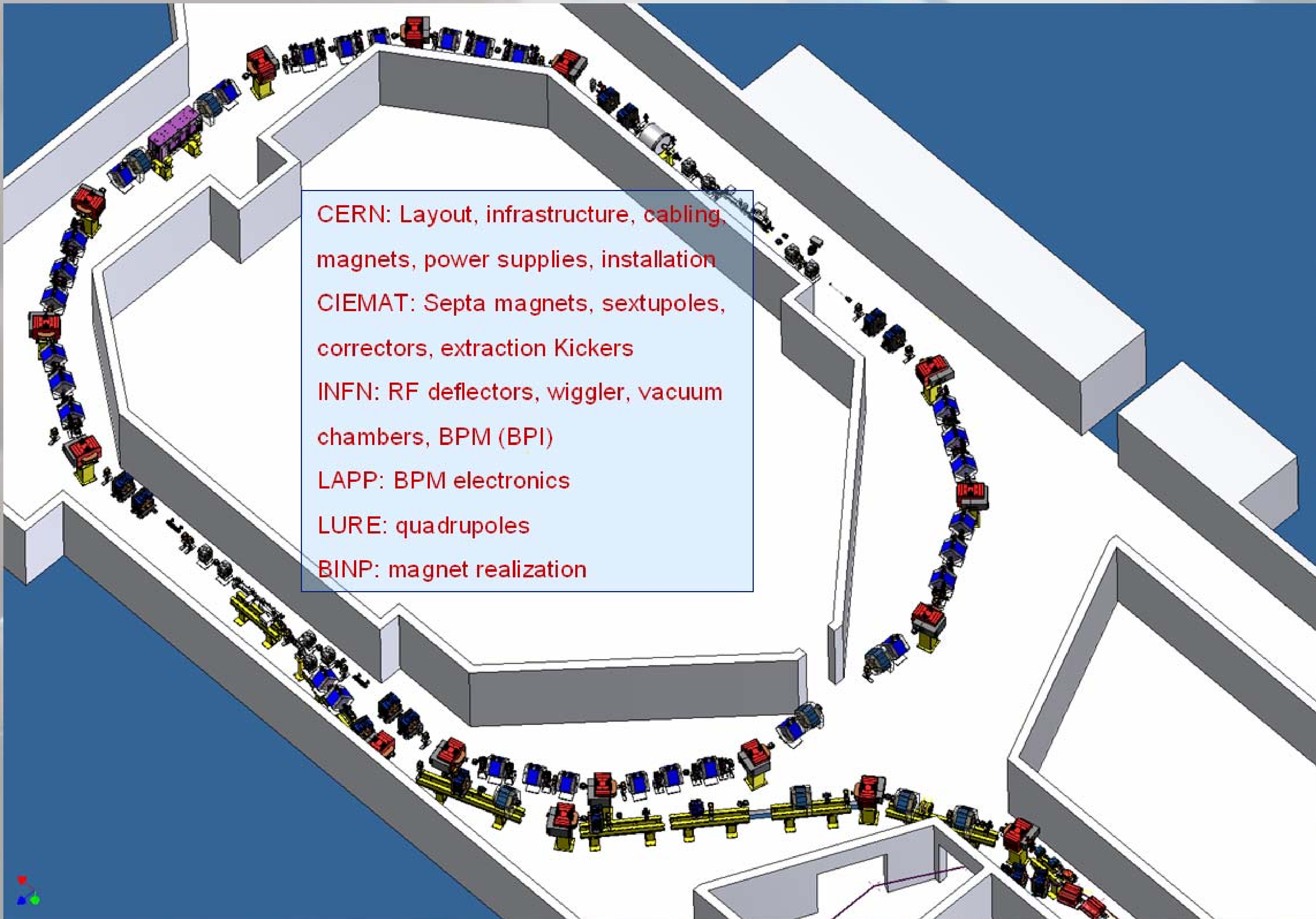
Results from CLIC proof of principle in CTF3



Results from CLIC proof of principle in CTF3



CERN: Layout, infrastructure, cabling, magnets, power supplies, installation

CIEMAT: Septa magnets, sextupoles, correctors, extraction Kickers

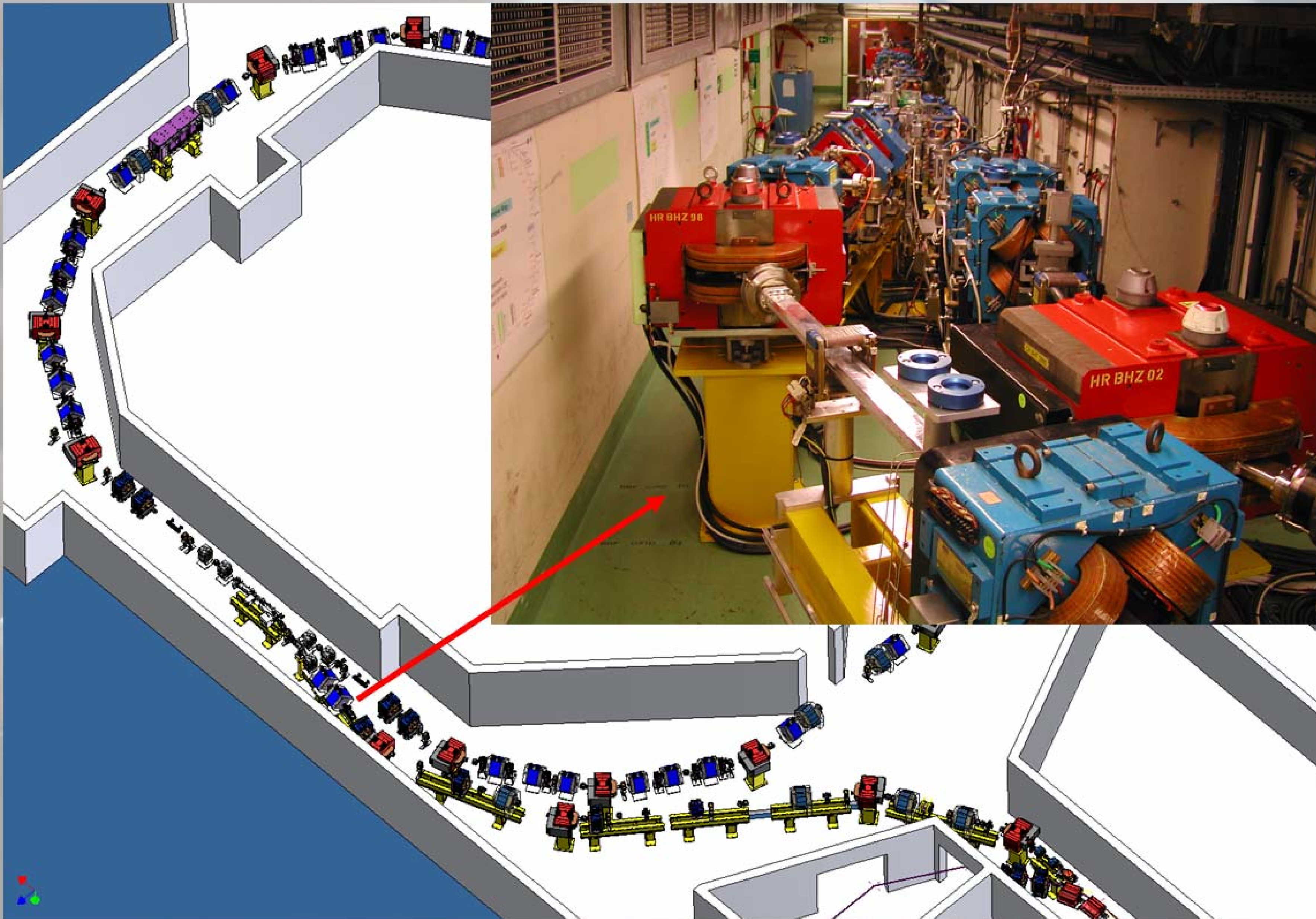
INFN: RF deflectors, wiggler, vacuum chambers, BPM (BPI)

LAPP: BPM electronics

LURE: quadrupoles

BINP: magnet realization

Results from CLIC proof of principle in CTF3



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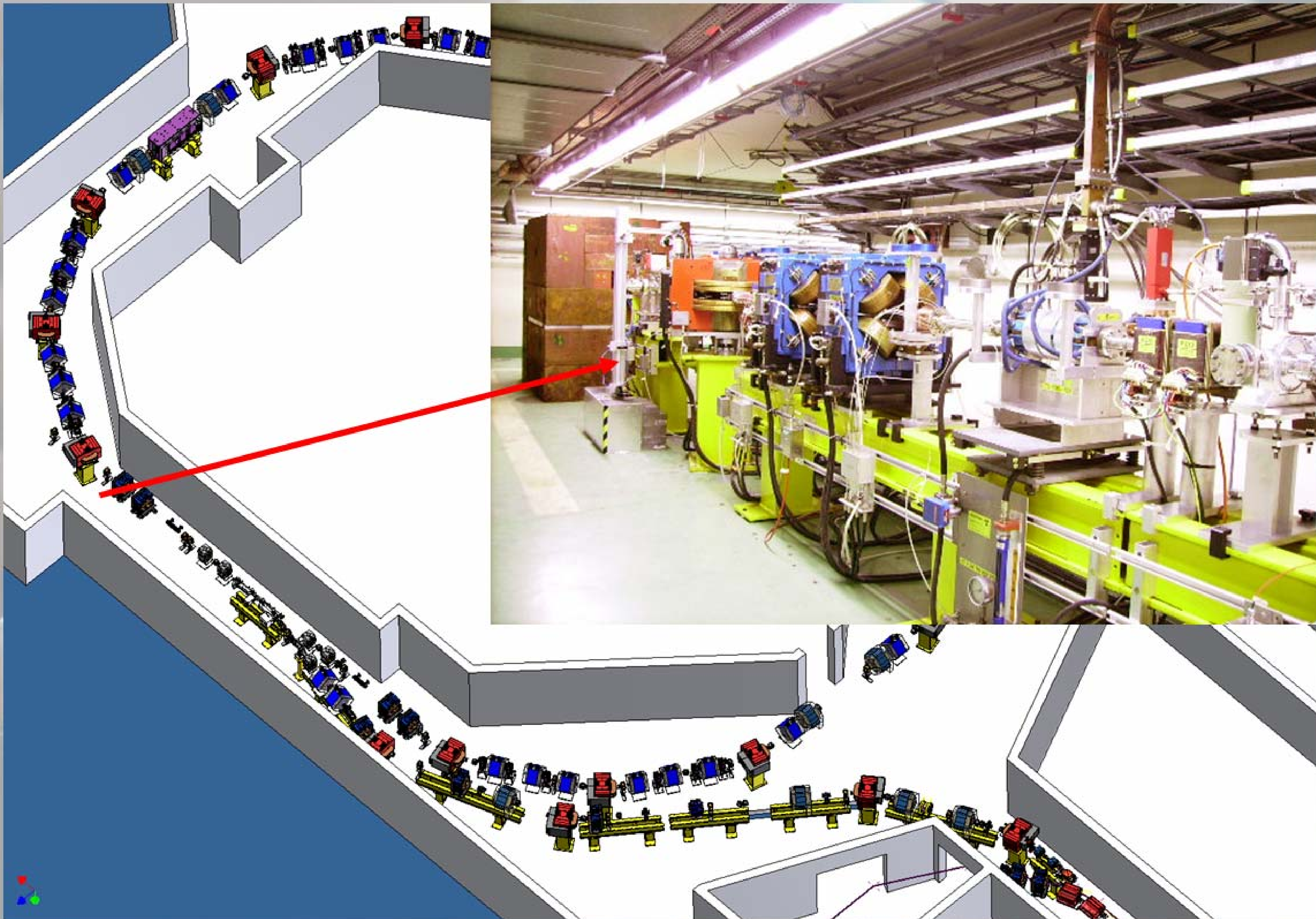

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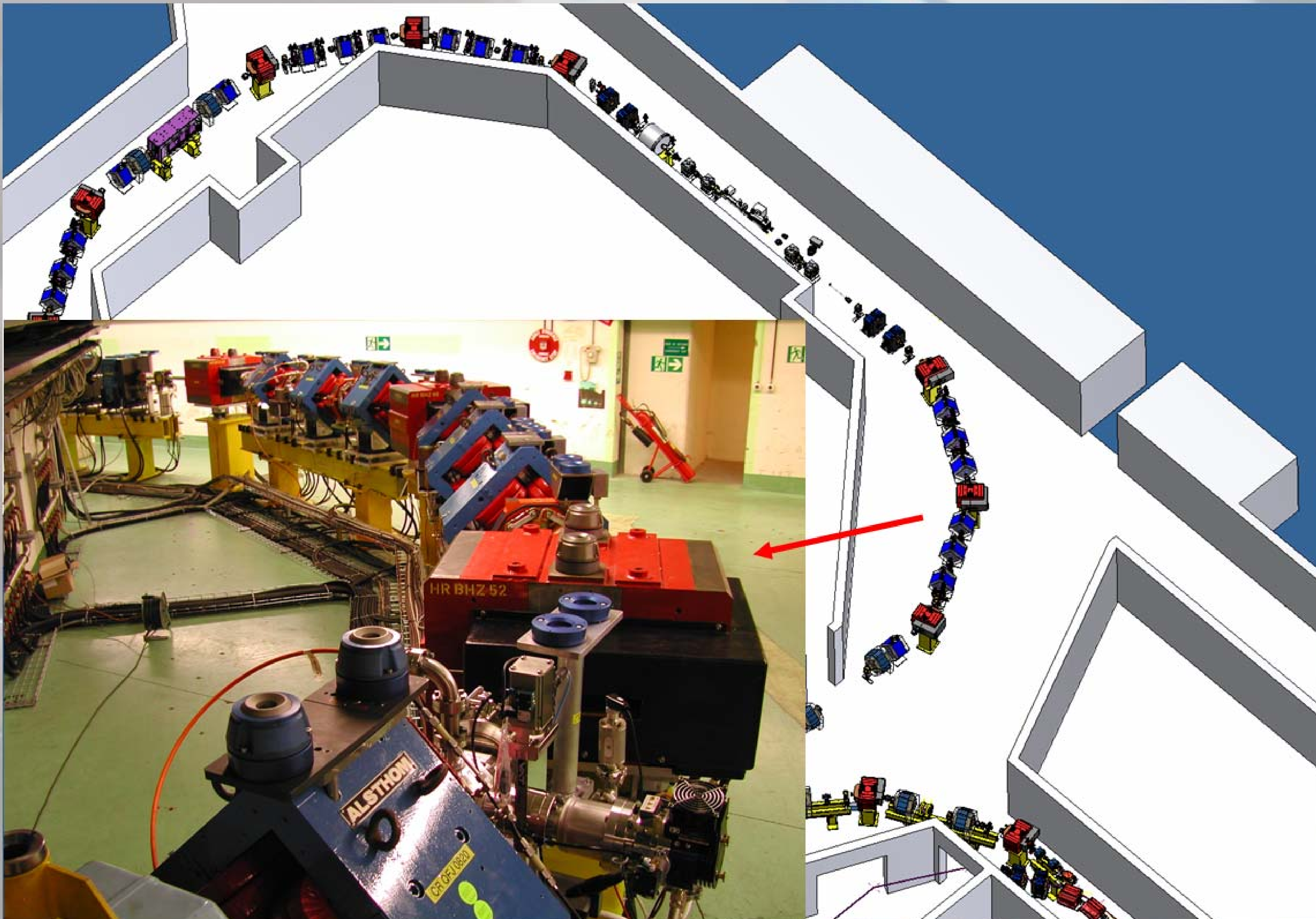
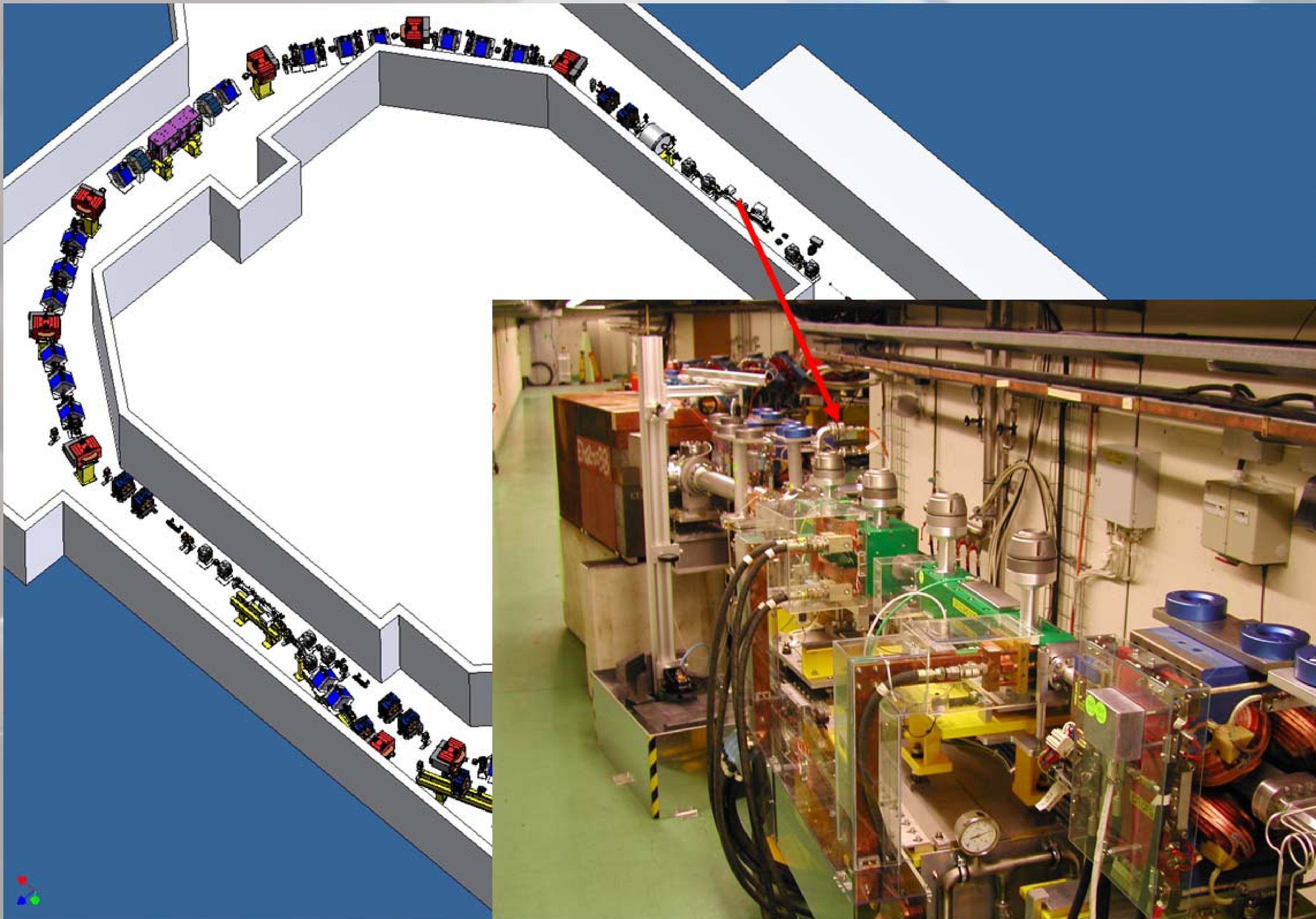
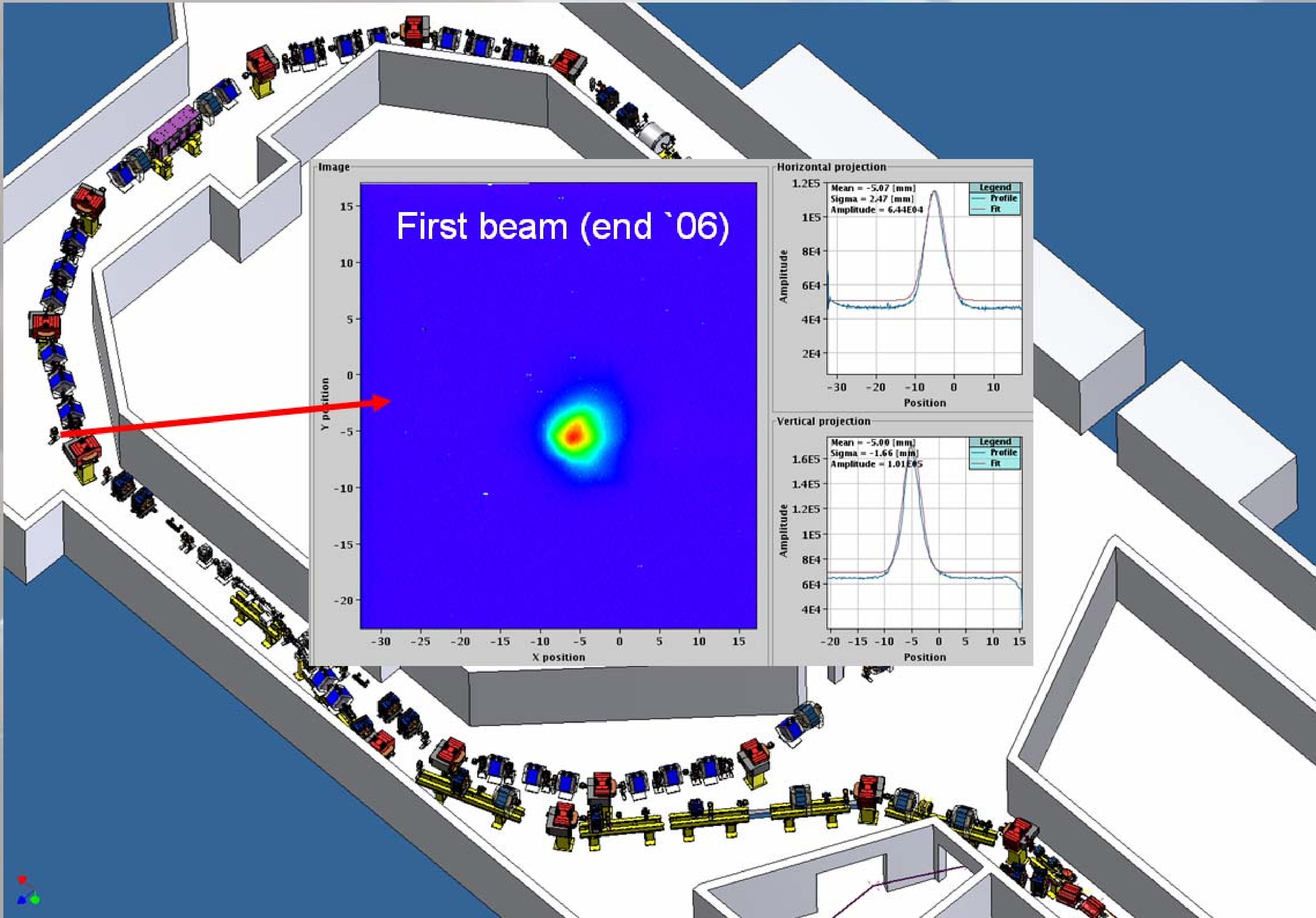
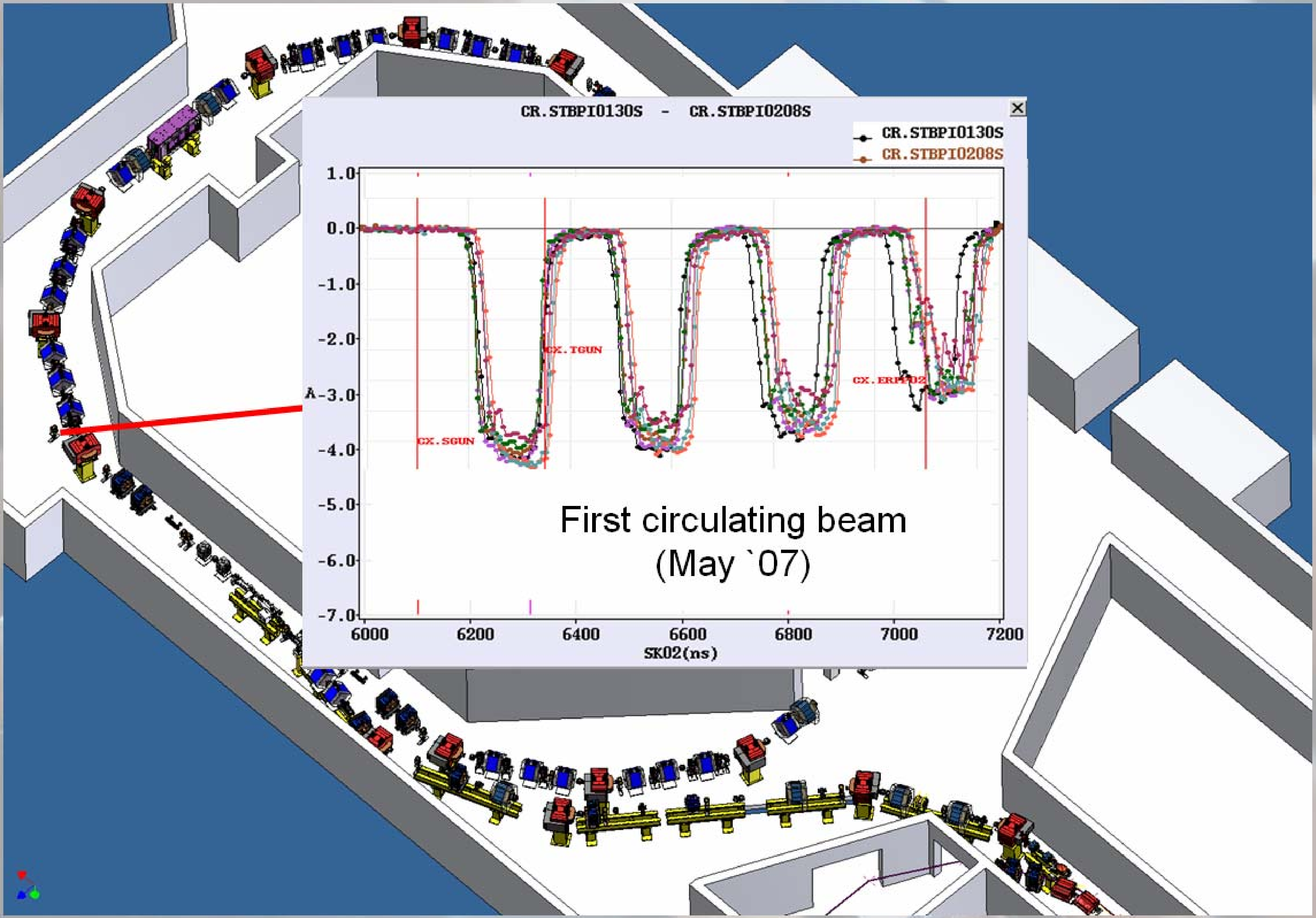
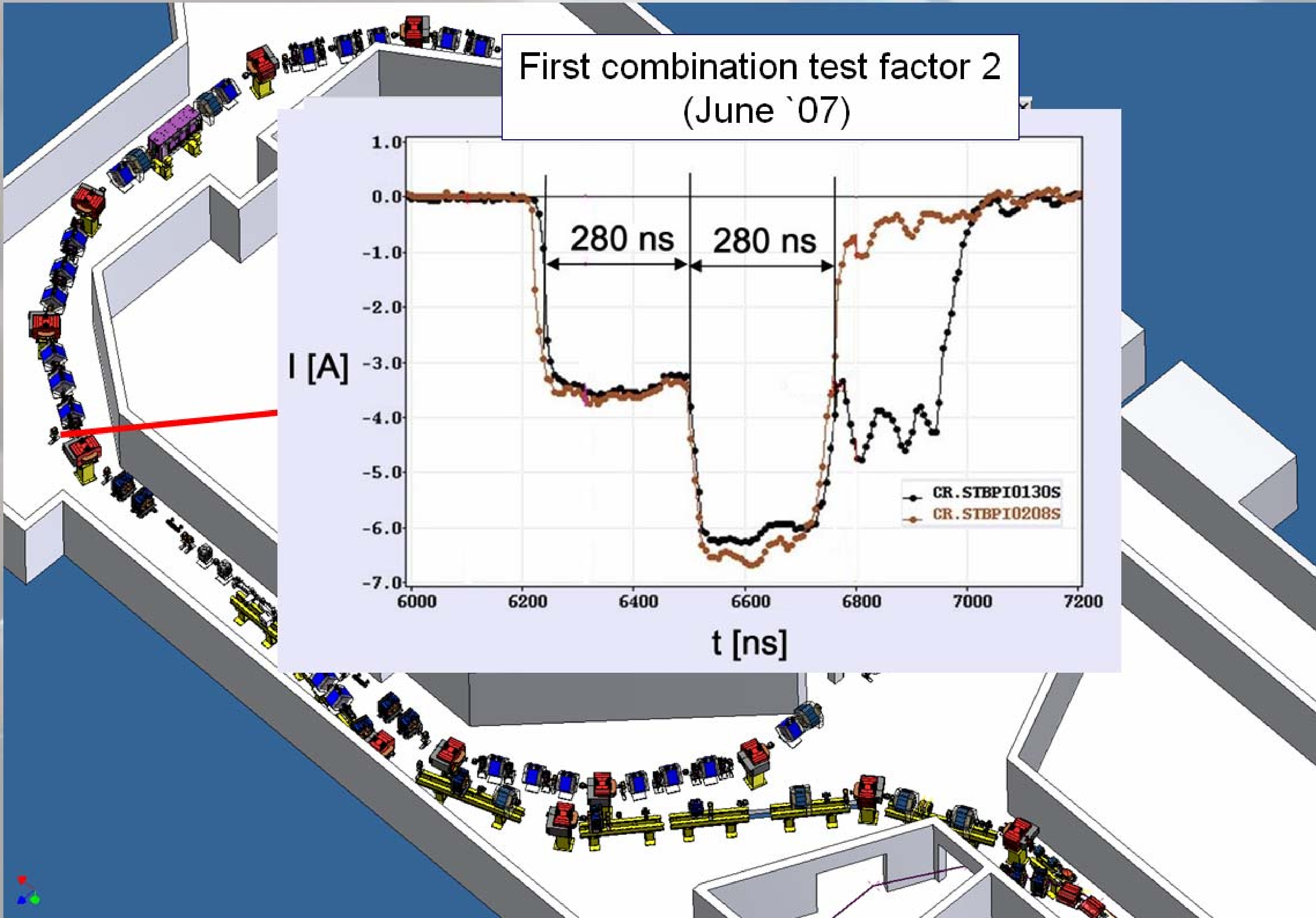





First beam (end `06)
Image
Y position
X position
Horizontal projection
Mean = -5.07 [mm]
Sigma = 2.47 [mm]
Amplitude = 6.44E04
Legend
Profile
Fit
Amplitude
Position
Vertical projection
Mean = -5.00 [mm]
Sigma = -1.66 [mm]
Amplitude = 1.01E05

Results from CLIC proof of principle in CTF3




First combination test factor 2
(June `07)
I [A]
t [ns]
280 ns
280 ns
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
6000
6200
6400
6600
6800
7000
7200
CR.STBPI0130S
CR.STBPI0208S

Summary of CTF3 Achievements

- *Production and stable acceleration of 4 A beam* with full pulse length without significant emittance growth. Wake-fields kept under control with HOM damping+detuning. Consistent with predictions from beam dynamics simulations.
- Measured *RF power to beam energy transfer efficiency of 95%* in fully loaded operation for normal conducting linac ! !
- Demonstration of *bunch frequency multiplication with delay loop* using RF deflector cavities and *phase coding with fast phase switch*. Key ingredient to achieve bunch train compression.
- *First circulating beam in combiner ring* and test of factor 2 combination.
- *Routine 24h, 7 days a week operation* of fully loaded linac for *30 GHz production* $\Rightarrow$ fully loaded operation can be very reliable and stable.

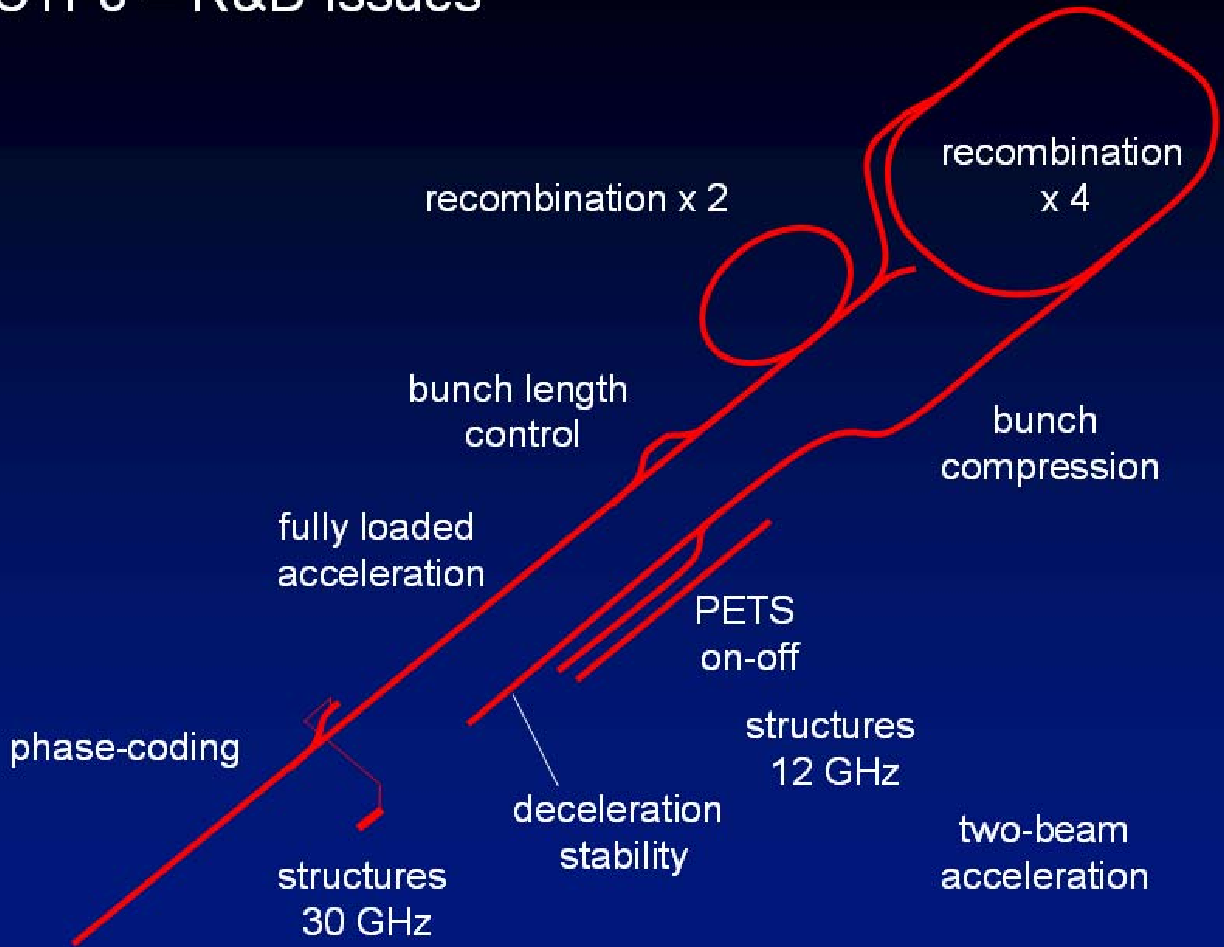
F. Tecker et al. THPMN063

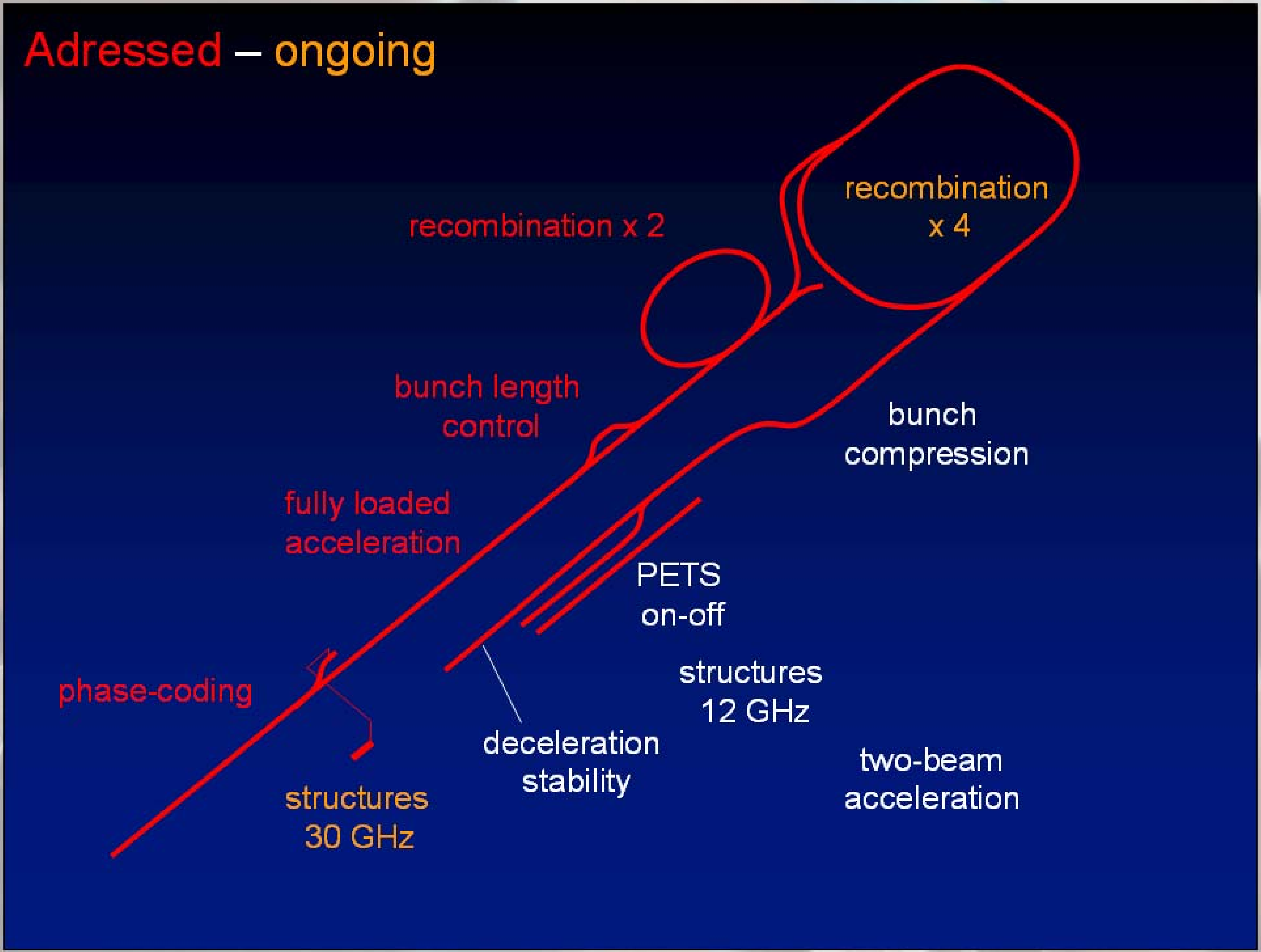
A. Dabrowski et al. FRPMS045

CLEX building

Construction on schedule
Equipment installation from May 2007,
Beam foreseen from March 2008

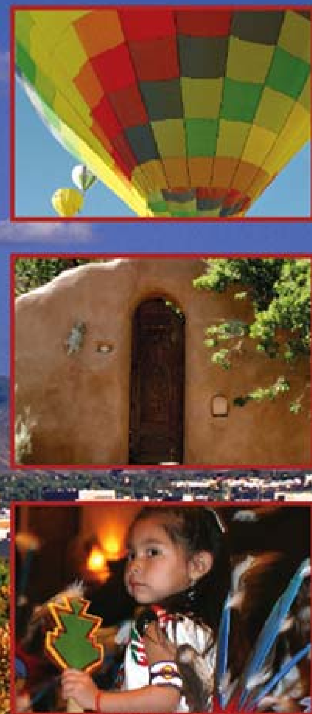
CTF3 – R&D Issues




Adressed – ongoing
recombination x 2
recombination
x 4
bunch length
control
bunch
compression
fully loaded
acceleration
PETS
on-off
phase-coding
structures
12 GHz
deceleration
stability
two-beam
acceleration
structures
30 GHz

Particle Accelerator Conference 2007

Albuquerque, New Mexico, June 25–29



Conclusions

- CTF3 has already demonstrated many CLIC critical issues
  - ✓ High-current fully-loaded acceleration
  - ✓ Phase-coding and delay loop recombination
- Results from structure tests in CTF3 have provided relevant information on structure limitations
- Based mainly on such result, CLIC key parameters have changed, now closer to optimum cost & efficiency
- CTF3 is on track to demonstrate the main CLIC feasibility issues by 2010. Collaboration modelled on large physics experiments is proving surprisingly efficient.