TWO-BEAM LINEAR COLLIDERS SPECIAL ISSUES

R. Corsini for the CLIC/CTF3 Collaboration

Talk outline

- Introduction - CLIC
- The Two-Beam Acceleration concept
  - Motivation and Initial Evolution of the Concept
  - The CLIC TBA
- Experimental results in CTF3
  - Past results
  - Present status
- Outlook

Aim of the CLIC study:

R. Tomas - FR1RAI01

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**,
- ✓L > few **10^{34} cm^{-2}** with acceptable background and energy spread
- ✓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

Complementary approach to ILC

The CLIC/ILC collaboration is preparing together the future evaluation of the two technologies by the Linear Collider community made up of CLIC & ILC experts

Two Beam Linear Colliders – Special Issues

R. Corsini, 8.5.2009

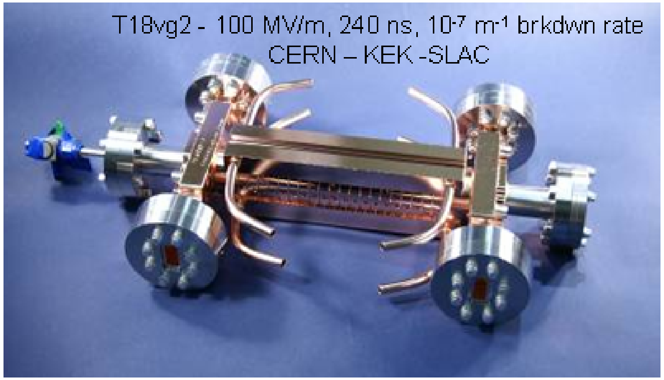
The CTF3 – CLIC world wide collaboration

28 institutes involving 18 funding agencies from 16 countries

Ankara University (Turkey)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
Gazi Universities (Turkey)
IRFU/Saclay (France)
Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
Instituto de Fisica Corpuscular (Spain)
INFN / LNF (Italy)
J.Adams Institute, (UK)
JINR (Russia)
JLAB (USA)
Karlsruhe University (Germany)
KEK (Japan)
LAL/Orsay (France)
LAPP/ESIA (France)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Oslo University (Norway)
PSI (Switzerland),
Polytech. University of Catalonia (Spain)
RRCAT-Indore (India)
Royal Holloway, Univ. London, (UK)
SLAC (USA)
Uppsala University (Sweden)

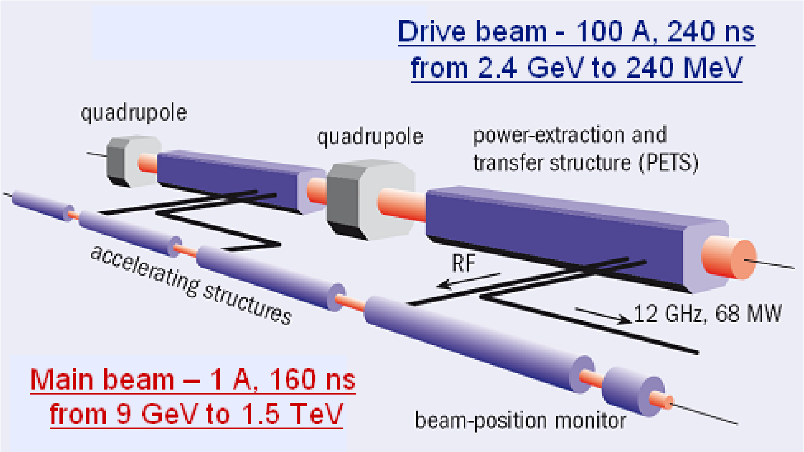
The CLIC way to a multi-TeV linear collider - Basic features

- High acceleration gradient (100 MV/m)
  - ✓ "Compact" collider - overall length @ 3 TeV < 50 km
  - ✓ Normal conducting accelerating structures
  - ✓ High acceleration frequency (12 GHz)

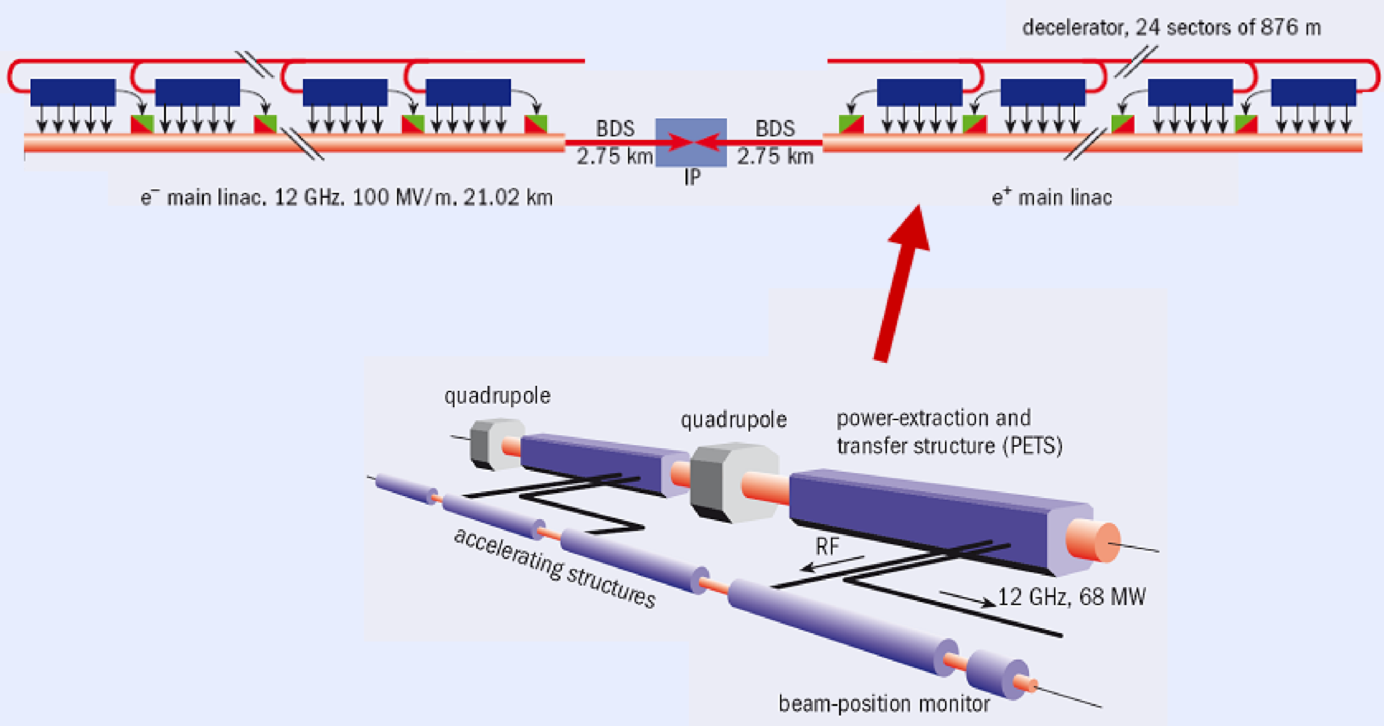


C. Adolphsen - WE5PFP018

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

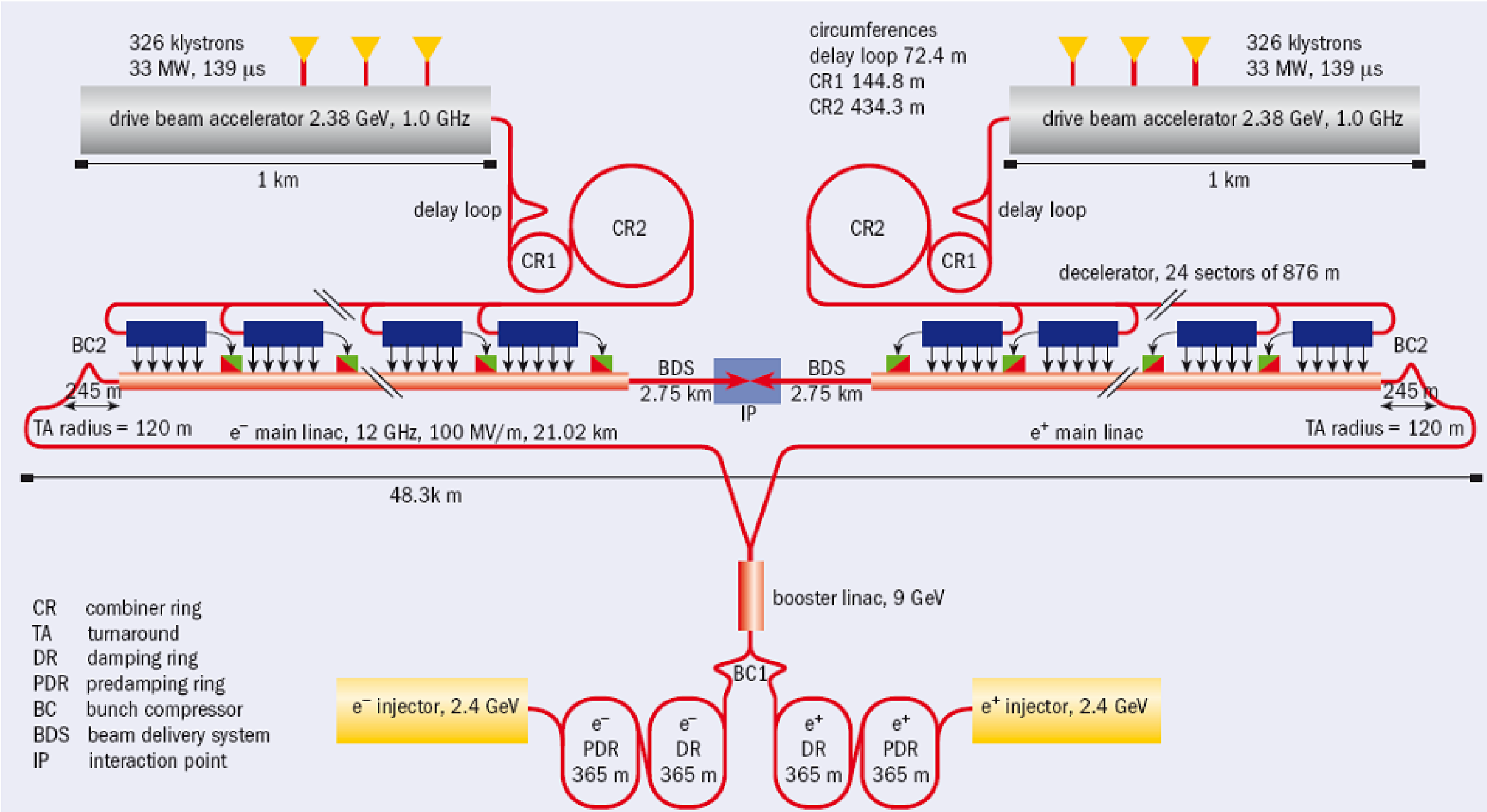


The CLIC Two-Beam Accelerator



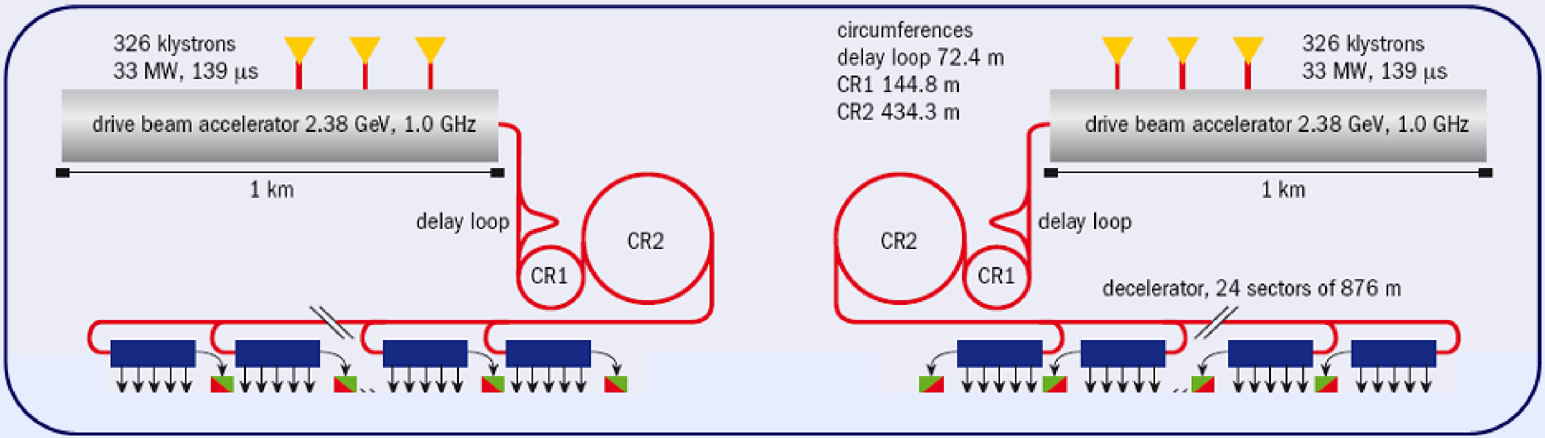
Two Beam Linear Colliders – Special Issues

R. Corsini, 8.5.2009



CLIC schematic layout @ 3 TeV

Two Beam Linear Colliders – Special Issues



CLIC RF power source

CLIC schematic layout @ 3 TeV

Why a Two-Beam scheme ?

Luminosity

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

- ✓ Luminosity scales as wall-plug-to-beam efficiency. Need to obtain at the same time high-gradient acceleration and efficient energy transfer.
- ✓ The use of high-frequency RF maximizes the electric field in the RF cavities for a given stored energy.
- ✓ However, standard RF sources scales unfavourably to high frequencies, both in for maximum delivered power and efficiency.
- ✓ A way to overcome such a drawback is to use standard low-frequency RF sources to accelerate the drive beam and use it to produce RF power at high frequency.
- ✓ The drive beam is therefore used for intermediate energy storage.

154

Laser Acceleration of Particles, P.J. Channel ed. (AIP Conf. No. 91, American Institute of Physics, New York 1982), p. 154-159.

THE FREE ELECTRON LASER AS A POWER SOURCE FOR A HIGH-GRADIENT ACCELERATING STRUCTURE*

Andrew M. Sessler

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

ABSTRACT

A two beam colliding linac accelerator is proposed in which one beam is intense (≈1kA), of low energy (≈ MeV), and long (≈ 100 ns) and provides power at 1 cm wavelength through a free-electron-laser-mechanism to the second beam of a few electrons (≈ 10^{11}), which gain energy at the rate of 250 MeV/m in a high-gradient accelerating structure and hence reach 375 GeV in 1.5 km. The intense beam is given energy by induction units and gains, and looses by radiation, 250 keV/m thus supplying 25 J/m to the accelerating structure. The luminosity, L, of two such linacs would be, at a repetition rate of 1 kHz, L = 4. x 10^{32} cm^{-2} s^{-1}.

A. Sessler, 1982

- ✓ RF frequency 30 GHz
- ✓ Drive beam acceleration by induction cells
- ✓ RF power extraction by FEL
- ✓ Re-acceleration

CERN-LEP-RF/86-06
and
CLIC NOTE 13
13.2.86

A TWO-STAGE RF LINEAR COLLIDER USING A SUPERCONDUCTING DRIVE LINAC

W. Schnell

Abstract

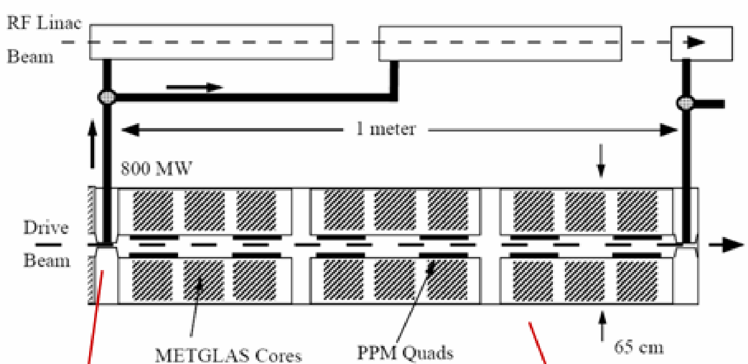
The efficiency from RF input to beam power of a normal conducting travelling-wave linac can be raised above 5% albeit at the price of a very short power pulse and an appreciable but probably correctible energy spread. Compensated multibunch operation may yield 30% efficiency but higher order wakefield problems have to be solved and a suitable final focus system must be found. The worst remaining problem seems to be the economic and efficient generation of peak RF power. The solution proposed here consists of a limited number of CW UHF klystrons, a superconducting UHF drive linac and a tightly bunched drive beam of several GeV average energy, transferring energy from the superconducting linac to the main linac via short sections of transfer structures. The power balance of this scheme is analysed and it is found that overall efficiency can be very high. Very dense drive bunches are required. Present-day performance of superconducting cavities is already sufficient to make the scheme viable at main linac accelerating gradients approaching 100 MV/m.

W. Schnell, 1986

- ✓ RF frequency from 6 GHz to 30 GHz
- ✓ Drive beam acceleration by super-conducting cavities
- ✓ RF power extraction by resonant structures (PETS)
- ✓ Re-acceleration

Two Beam Linear Colliders – Special Issues

HD-TBA Extraction Section.



Relativistic Klystron TBA LBL/LBNL

- ✓ RF frequency ~ 30 GHz
- ✓ Drive beam acceleration by induction cells
- ✓ RF power extraction by resonant structures
- ✓ Re-acceleration

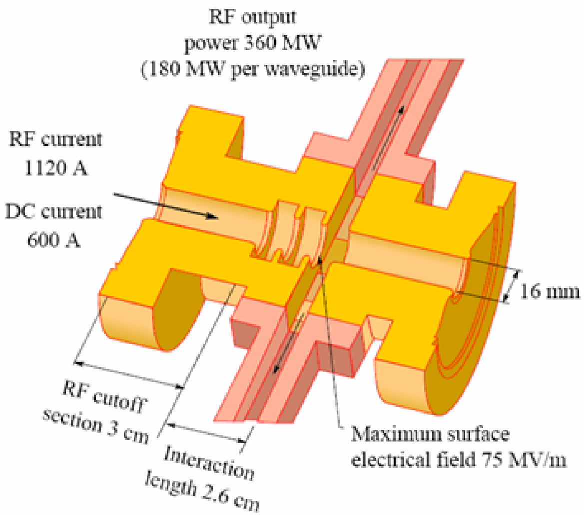
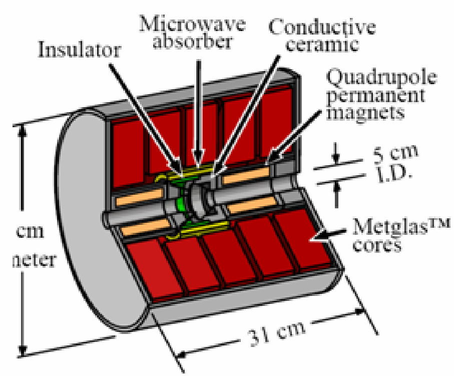
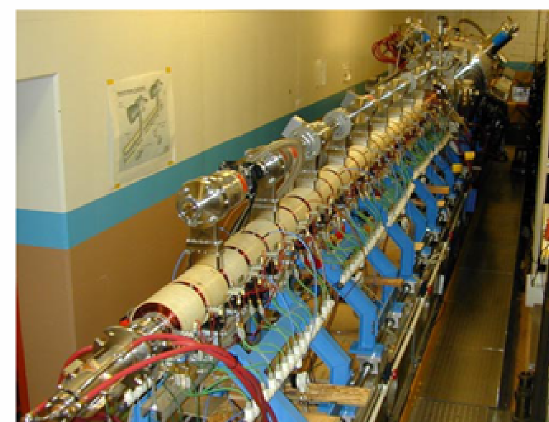


Illustration of an rf extraction structure.

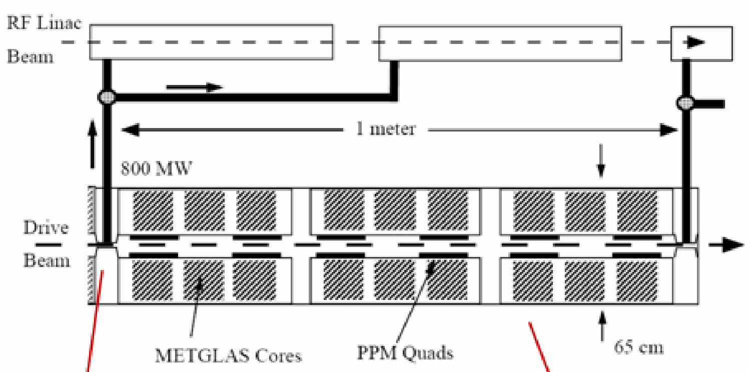


Proposed RK induction cell design.



RK-TBA Test Accelerator

HD-TBA Extraction Section.



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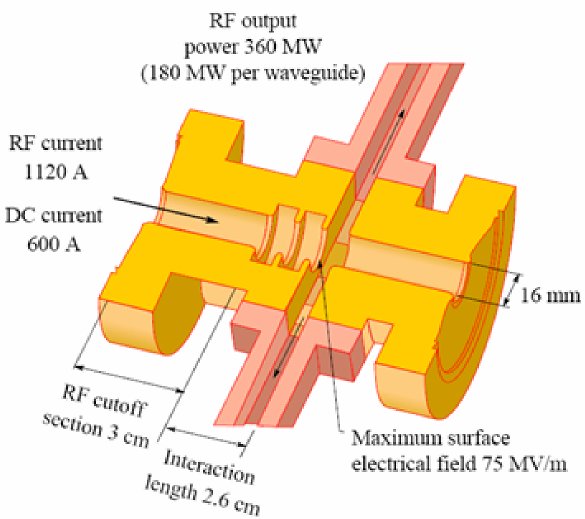

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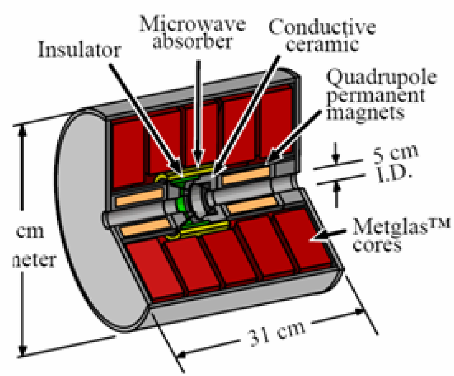


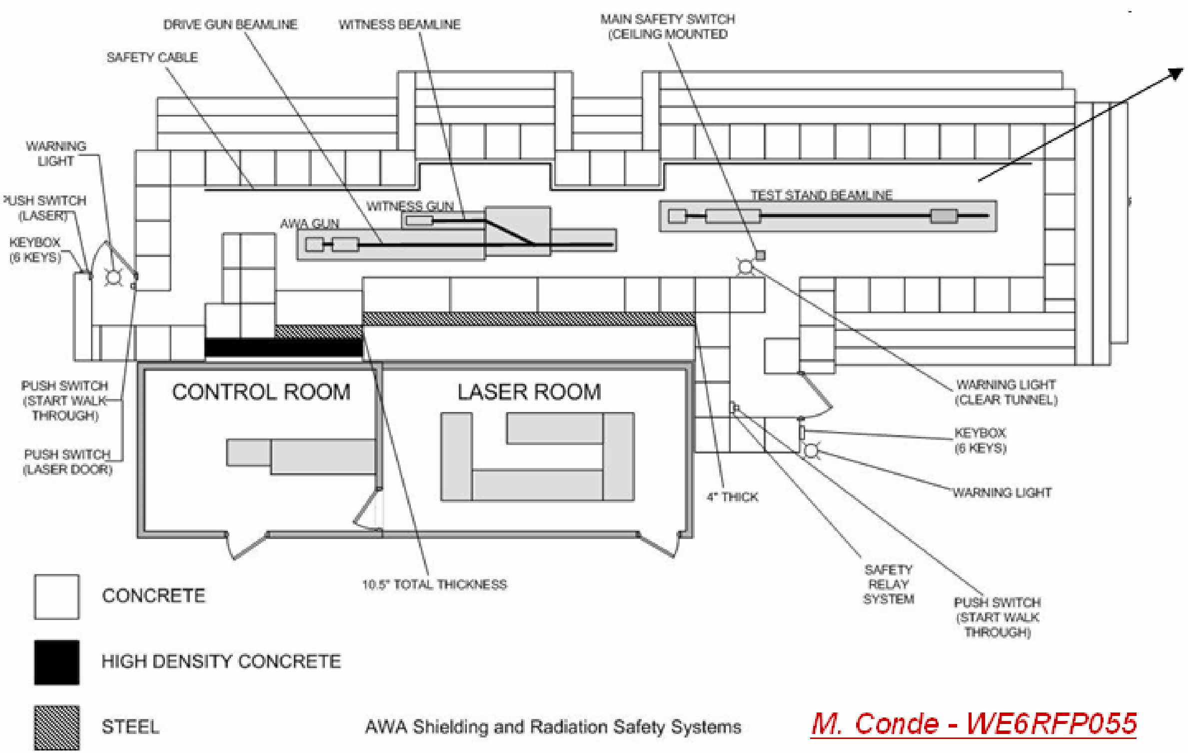
Proposed RK induction cell design.

Main issues

- ✓ Huge drive beam current, low energy
- ✓ Drive Beam transverse and longitudinal stability
- ✓ Cost of induction units
- ✓ Repetition rate
- ✓ Active elements in tunnel

Two-beam experiments at Argonne Wakefield Accelerator

- Wakefield acceleration in dielectric, iris loaded and photonic band gap structures
- Collinear two-beams
- Generation of high power cm wavelength RF
- Beam-driven plasma-based techniques



AWA Shielding and Radiation Safety Systems

M. Conde - WE6RFP055

RF frequency: 1.3 GHz

Photoinjector: 1½ cell, Mg photocathode

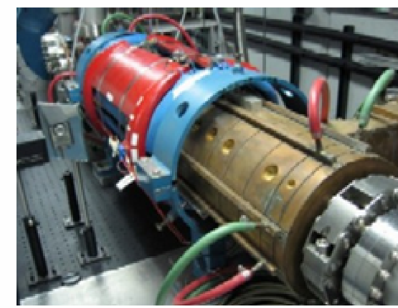
Charge per bunch: 1 to 100 nC

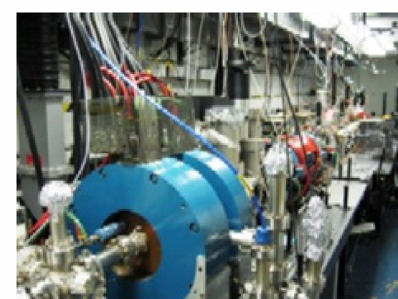
Bunch length: 14 ps FWHM

Maximum energy: 14 MeV

Length: ~7 meters

Being upgraded





The CLIC scheme - 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*

650 Klystrons

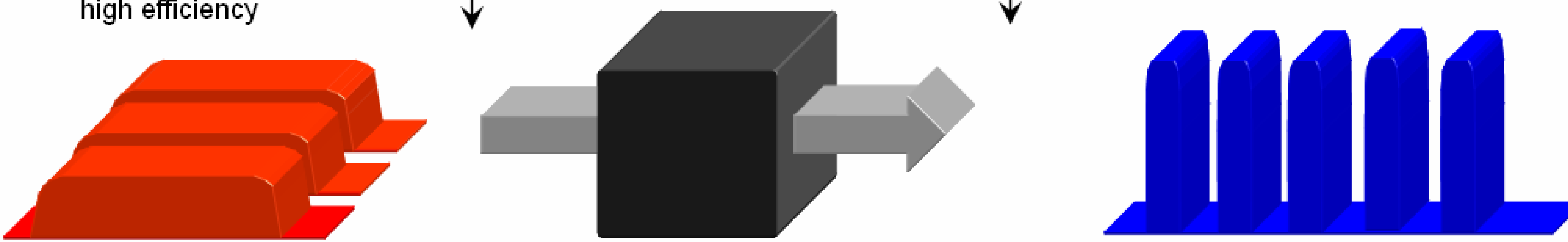
low frequency
high efficiency

Power stored in electron beam

Power extracted from beam in resonant structures

140000 Accelerating Structures

high frequency high gradient



Long RF Pulses

P_0 , n_0 , τ_0

Electron beam manipulation

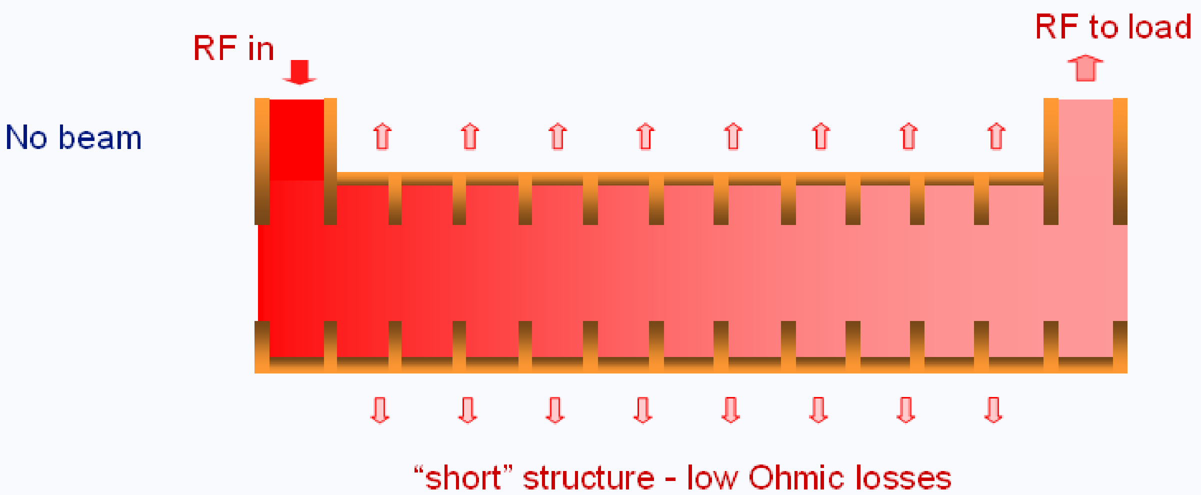
Short RF Pulses

$P_A = P_0 \times N_1$

$\tau_A = t_0 / N_2$

$\nu_A = \nu_0 \times N_3$

Full beam-loading acceleration in TW sections



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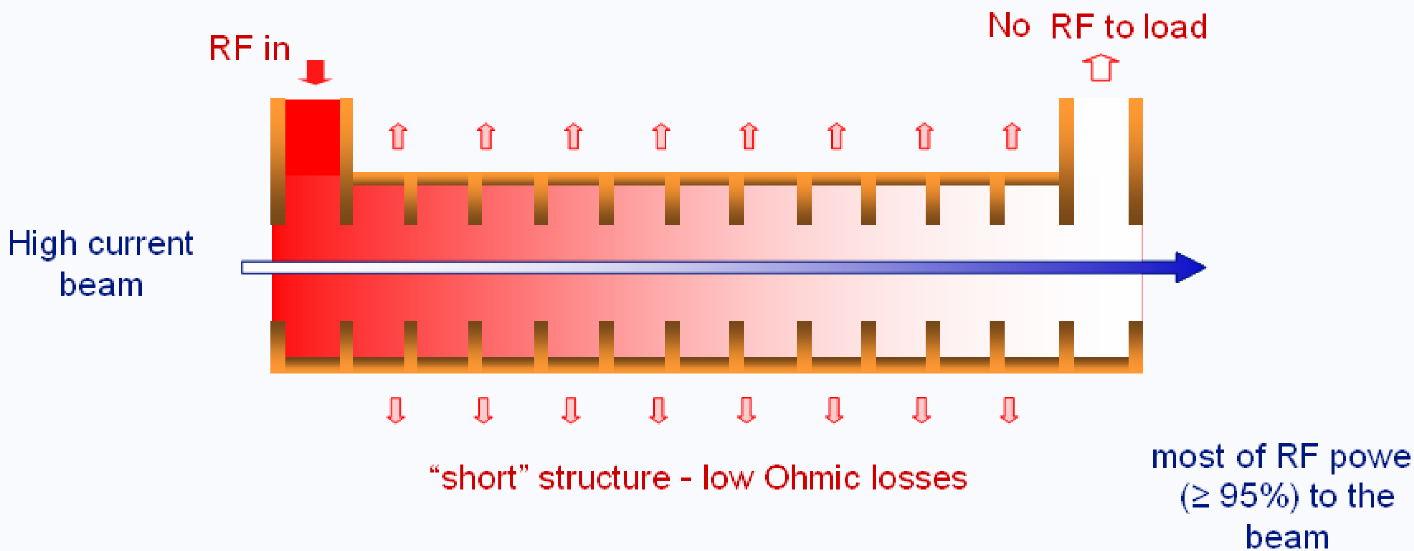

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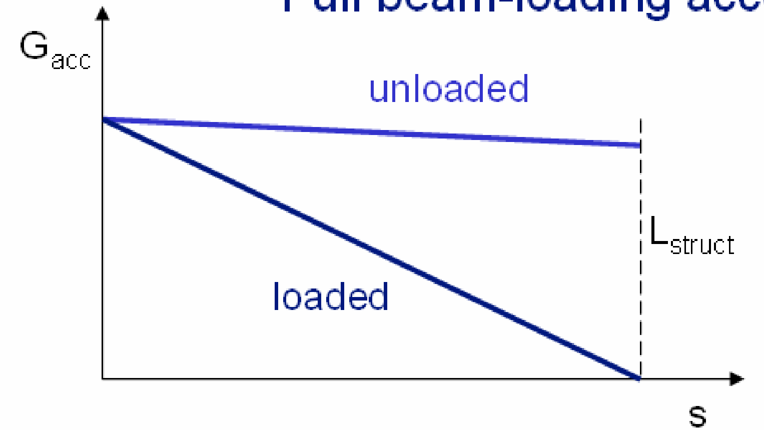
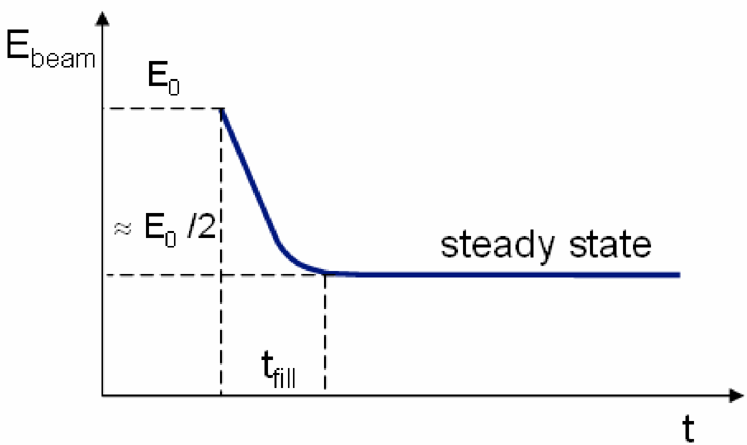
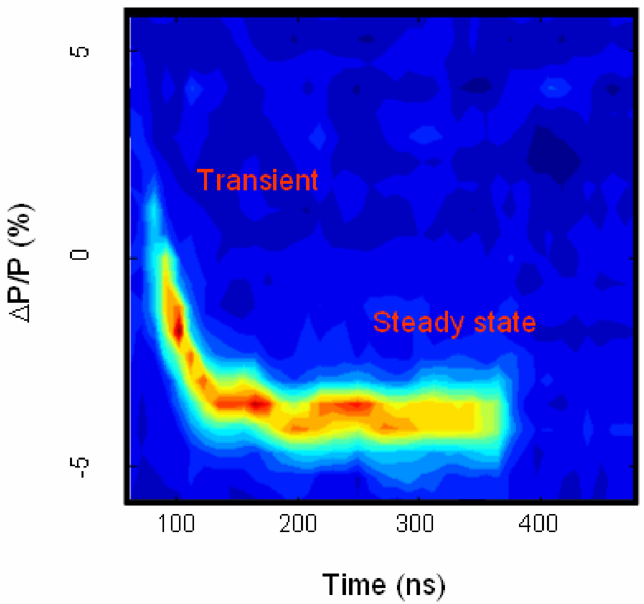
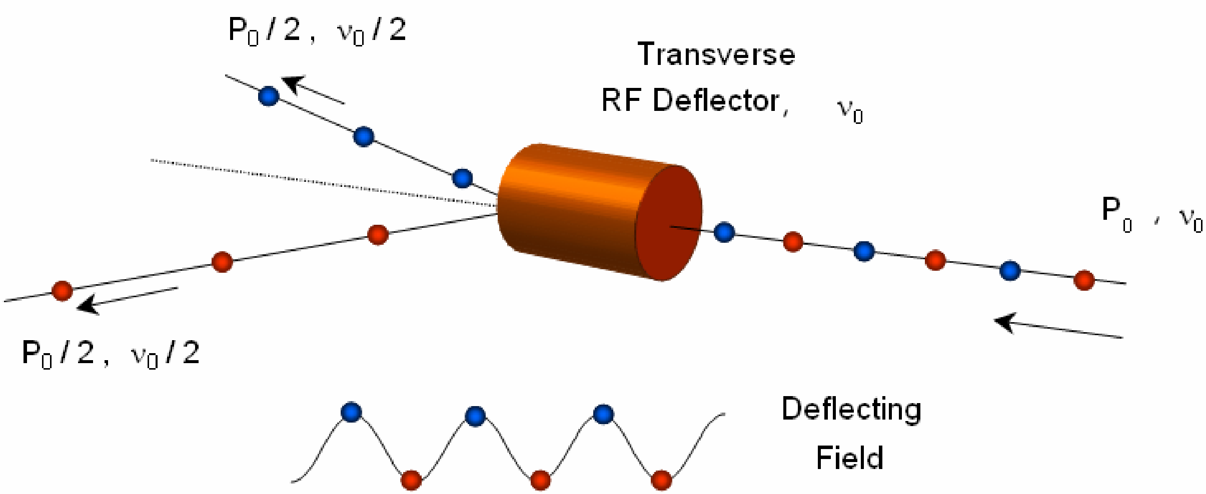




Time resolved beam energy spectrum measurement in CTF3



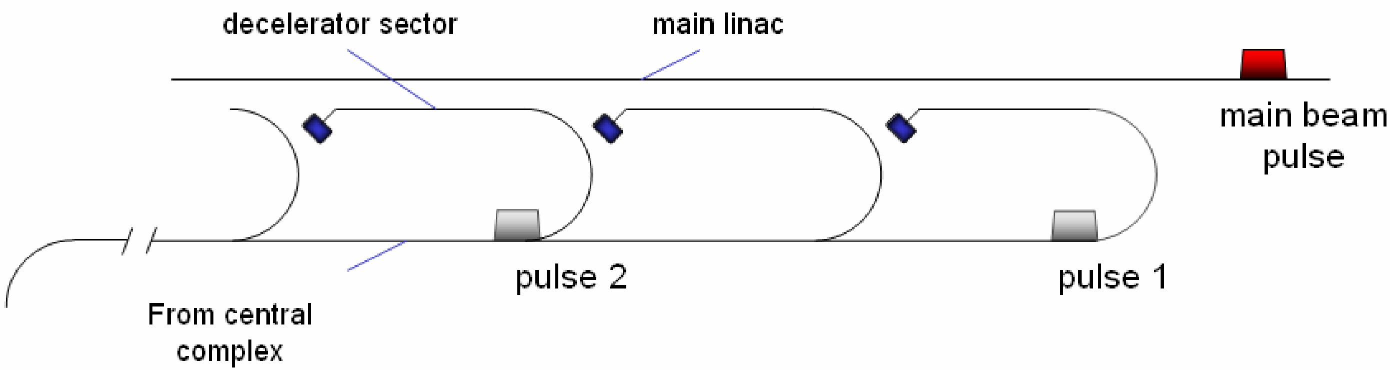
Beam combination/separation by transverse RF deflectors



Counter flow distribution

Counter propagation from central complex

Instead of using a single drive beam pulse for the whole main linac, several (N_S = 24) short ones are used.
Each one feed a 900 m long sector of TBA.



(DLDS-like system)

Counter-flow distribution allows to power different sectors of the main linac with different time bins of a single long electron pulse.
The distance between pulses is $2\ L_S = 2\ L_{main}/N_S$. The initial drive beam pulse length is equal to $2\ L_{main} = 140\ \mu s/c$.

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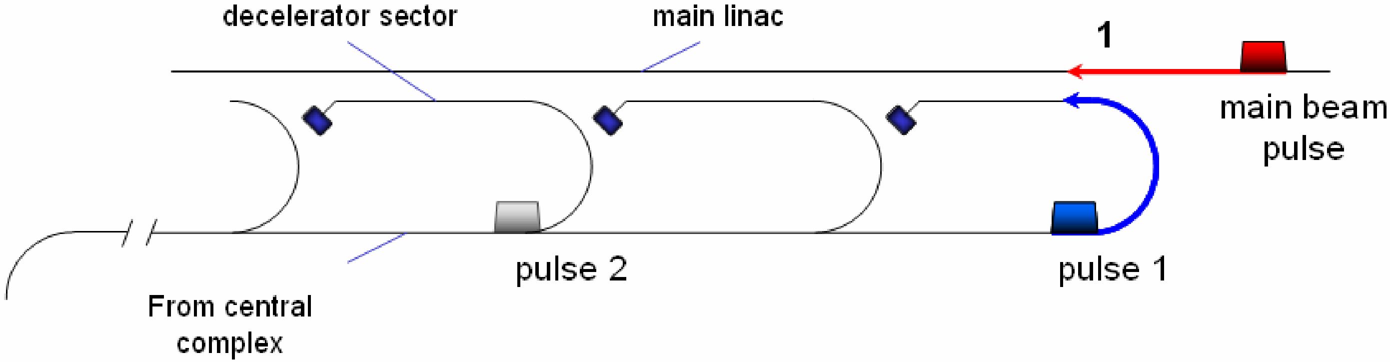

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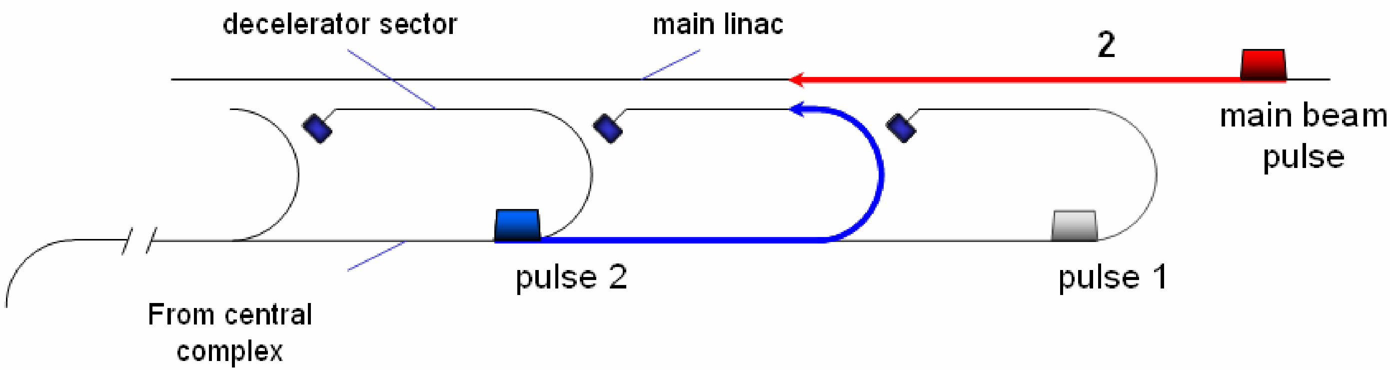

(DLDS-like system)

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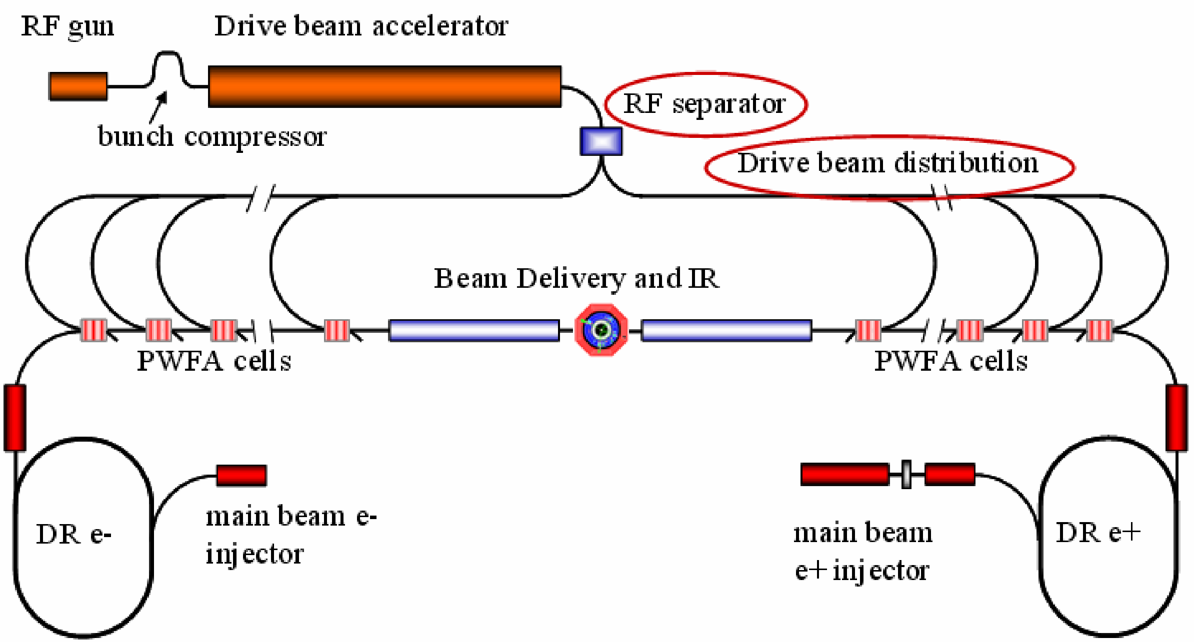
The distance between pulses is 2 L_S = 2 L_{main}/N_S. The initial drive beam pulse length is equal to 2 L_{main}= 140 μs/c.

Use of drive beam in Plasma Wakefield Accelerator



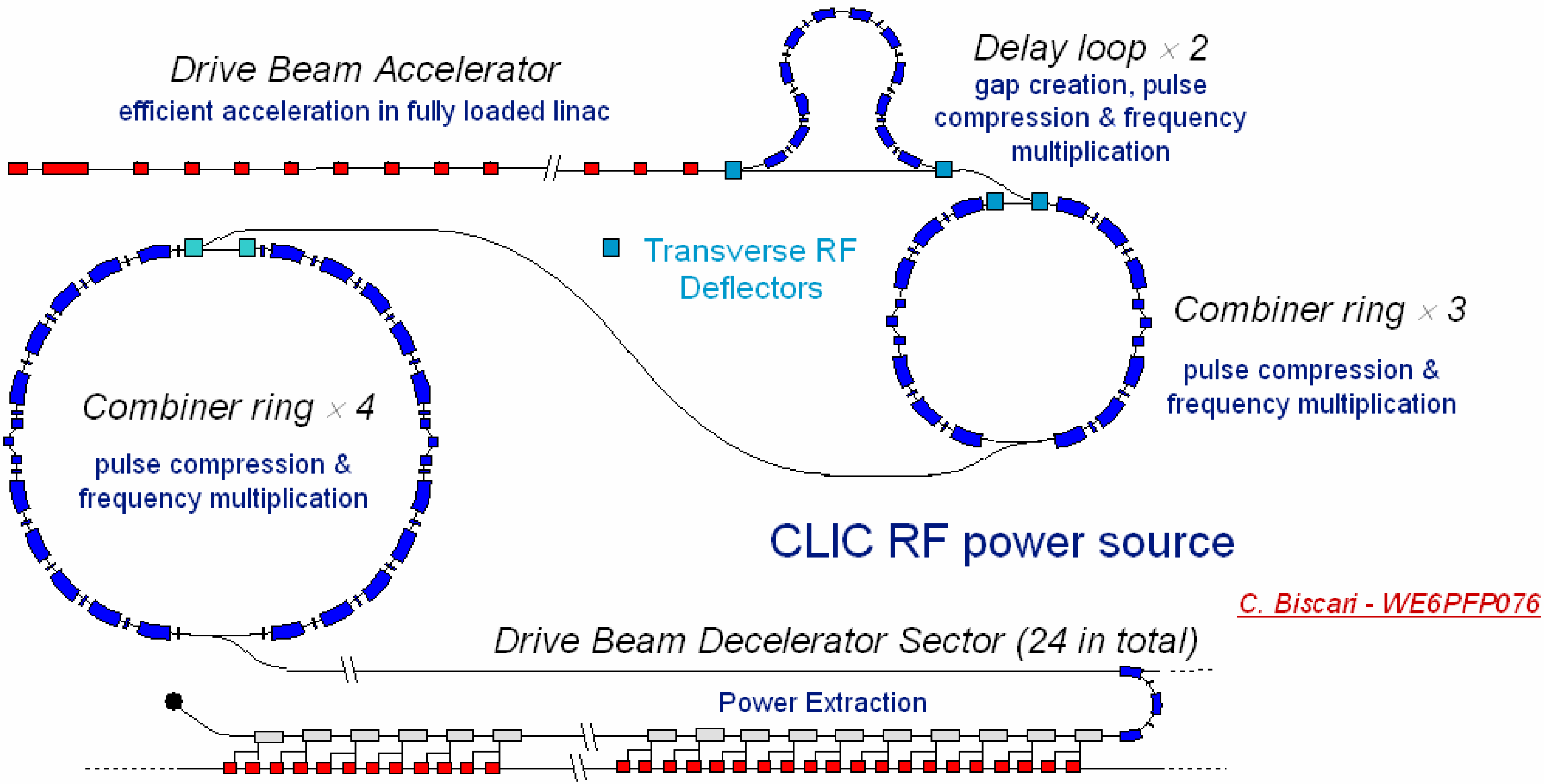
Concept for multi-stage PWFA Linear Collider

(collinear two-beam accelerator)

A. Seryi - WE6PFP079

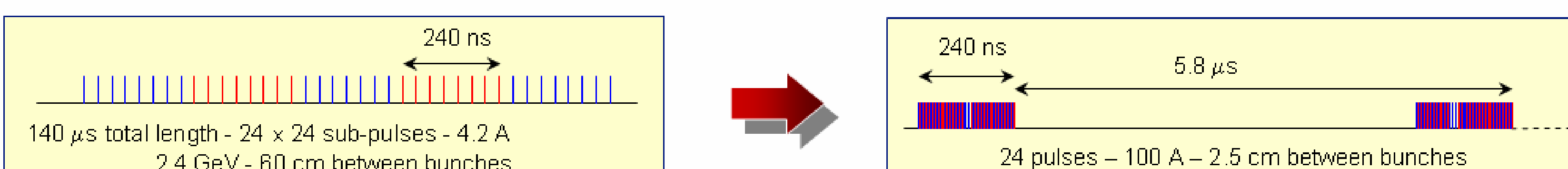
Two Beam Linear Colliders – Special Issues

R. Corsini, 8.5.2009



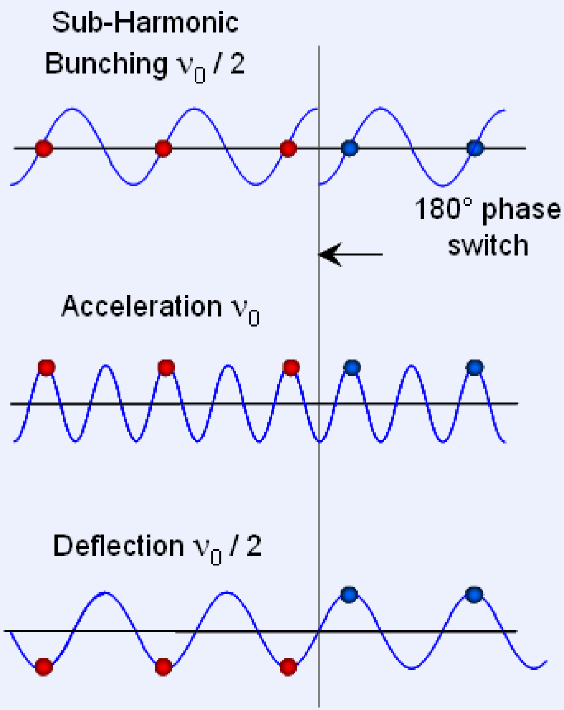
Drive beam time structure - initial

Drive beam time structure - final



Phase coding

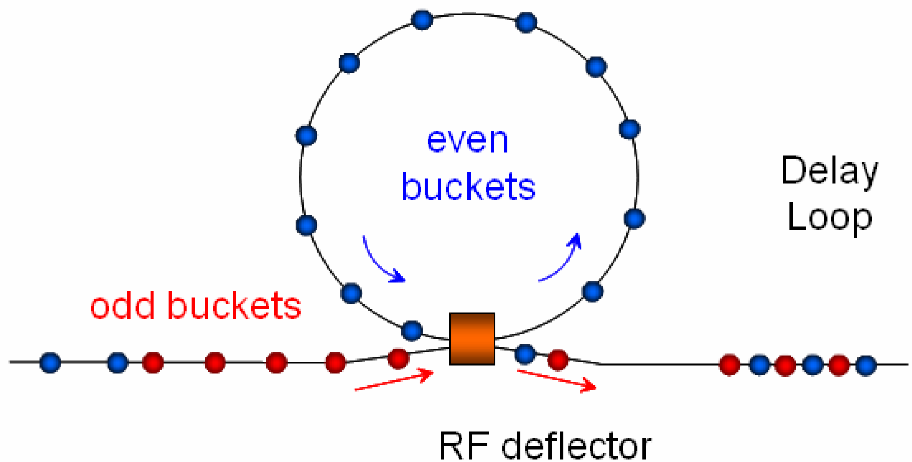
How to "code" the sub-pulses



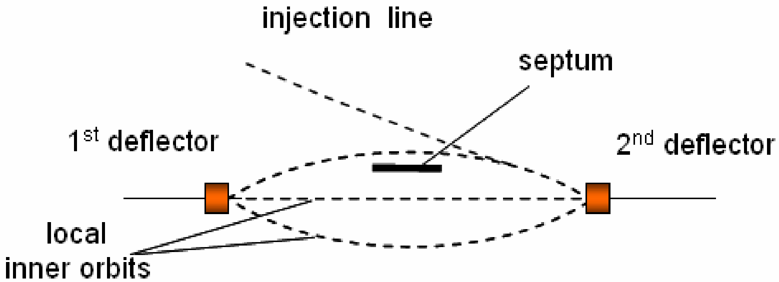
Gap creation & first multiplication × 2

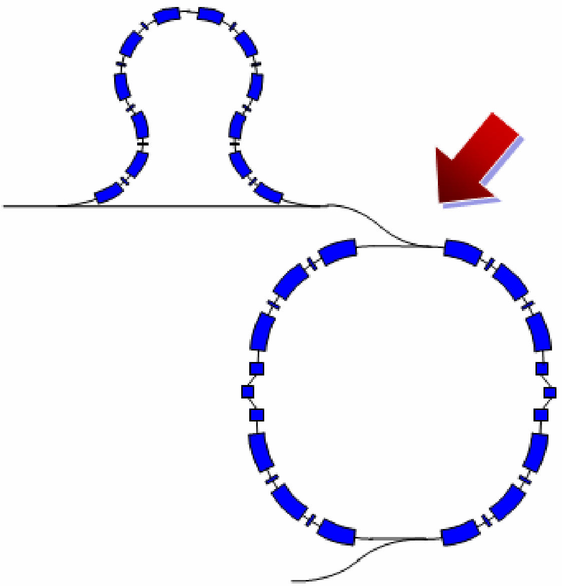
$$L_{delay} = n\,\lambda_0 = c\,T_{sub\text{-}pulse}$$

Combination scheme



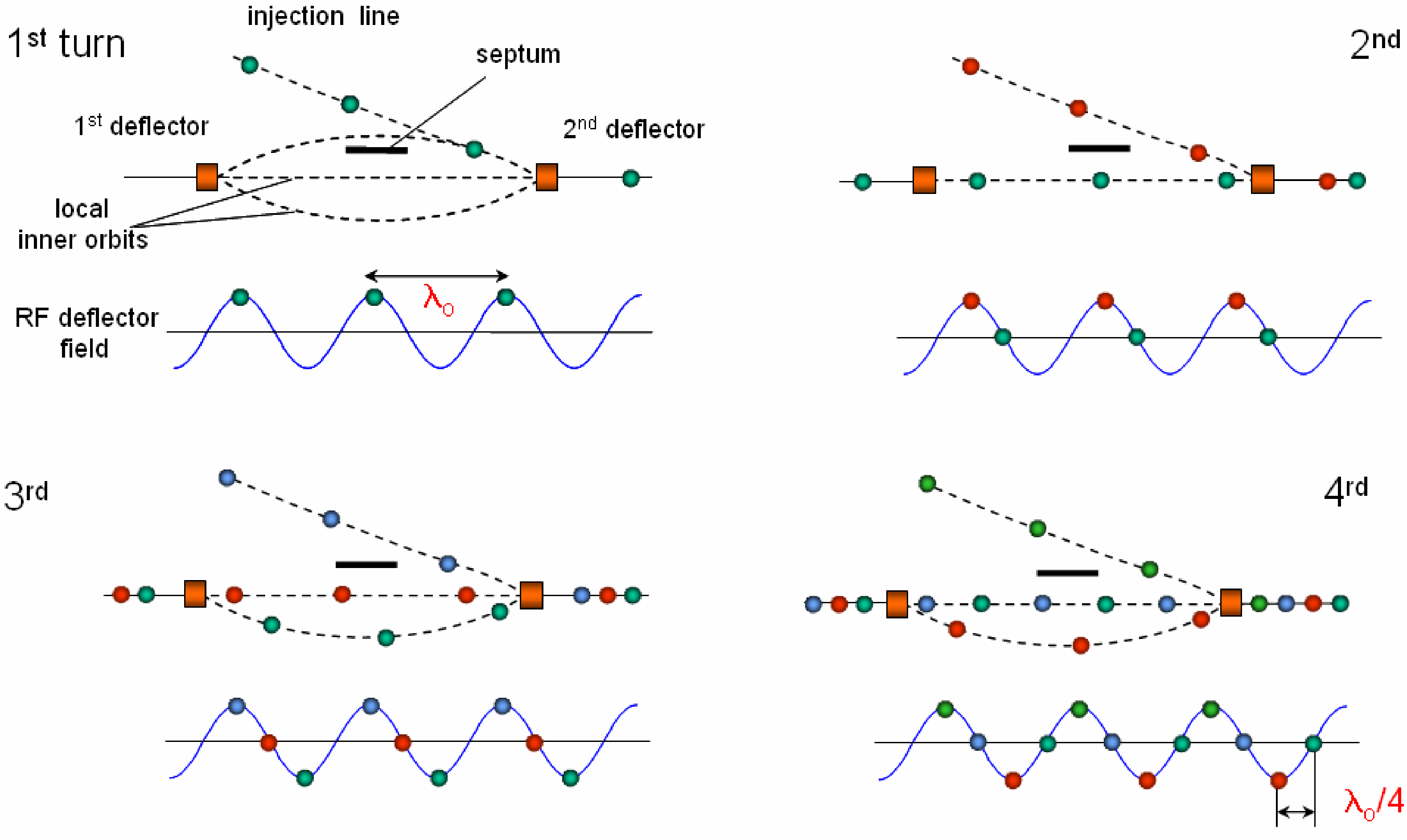
RF injection in combiner ring



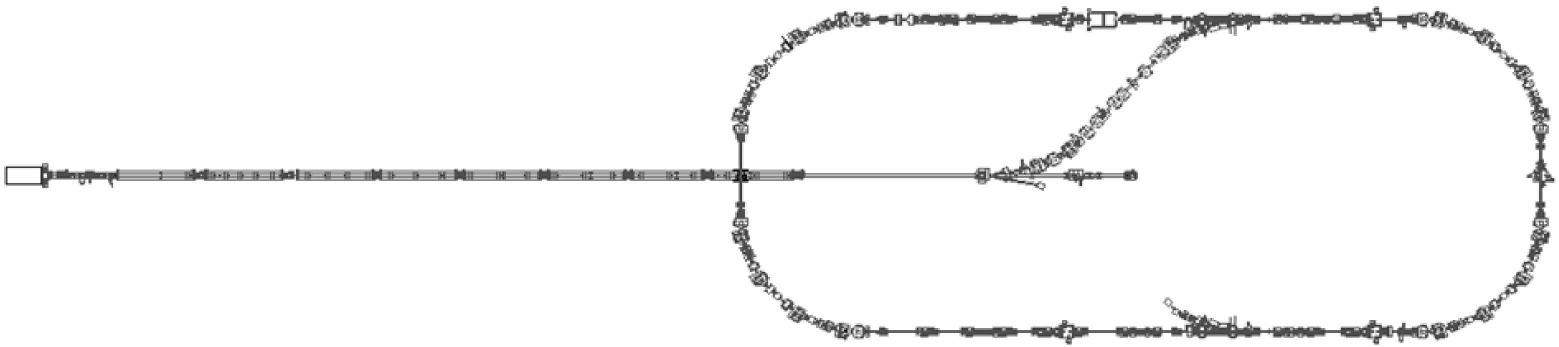


RF injection in combiner ring

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

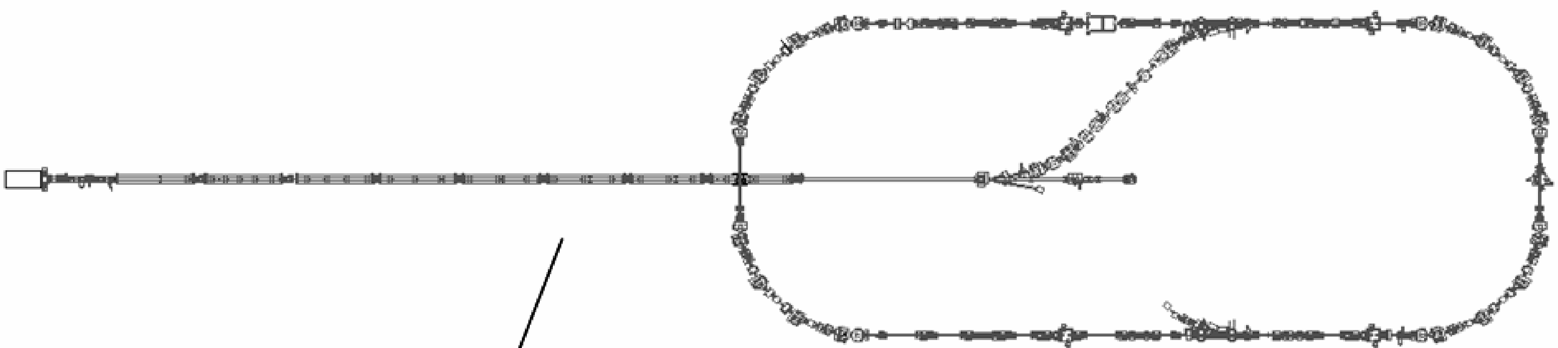


CTF3 preliminary phase (2001-2002)

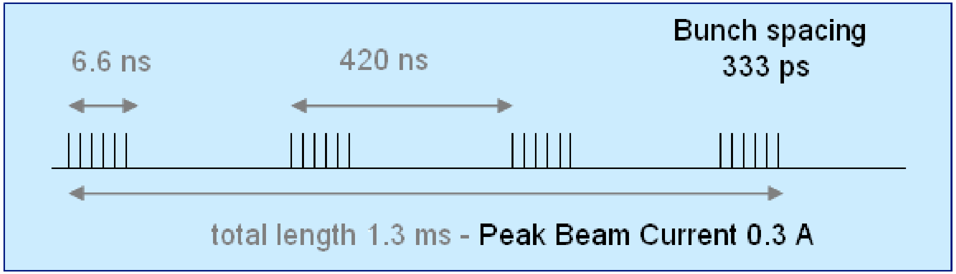


A first ring combination test was performed in 2002, *at low current and short pulse*, in the CERN Electron-Positron Accumulator (EPA), properly modified

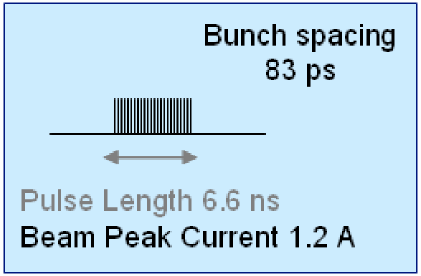
CTF3 preliminary phase (2001-2002)



Beam structure in linac – 4 pulses

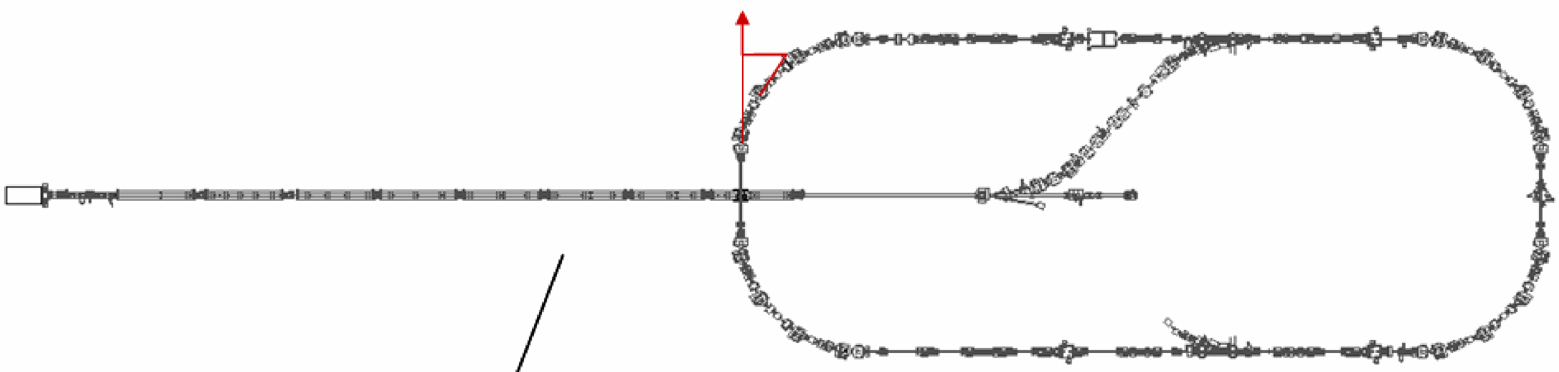


Beam structure after combination (factor 4)



CTF3 preliminary phase (2001-2002)

streak camera
measurement



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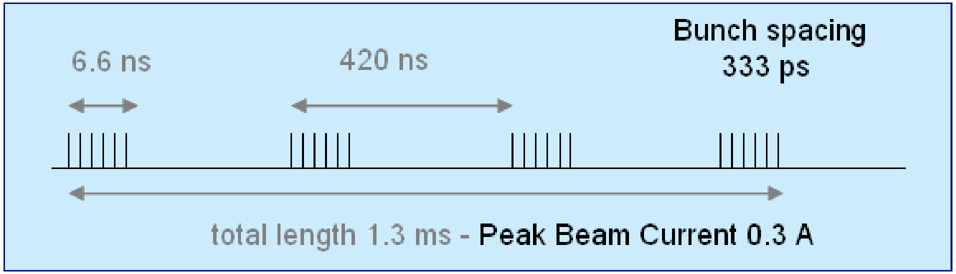
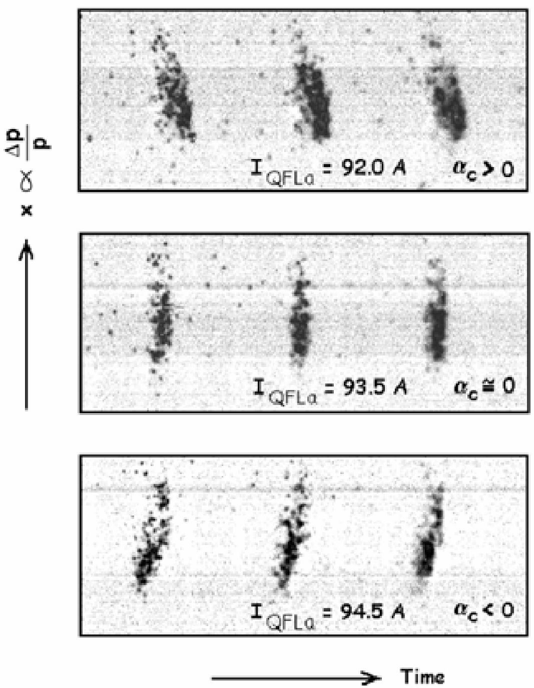
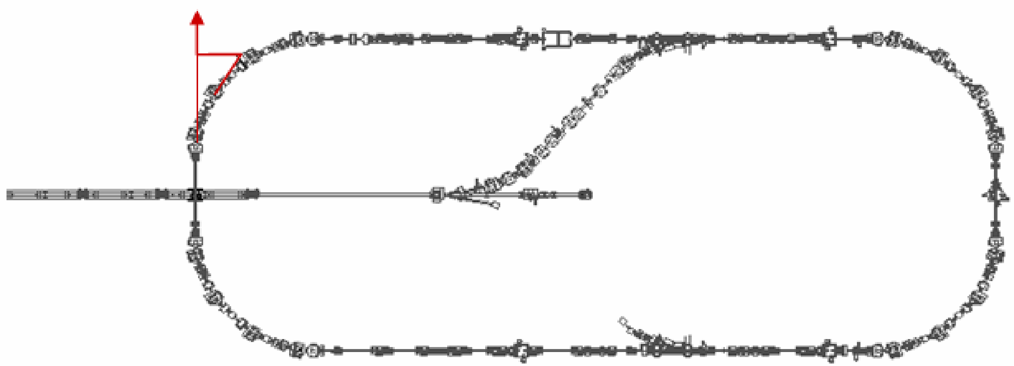


CTF3 preliminary phase (2001-2002)

Transition through zero momentum compaction optics - $\alpha \leq 10^{-4}$



streak camera measurement



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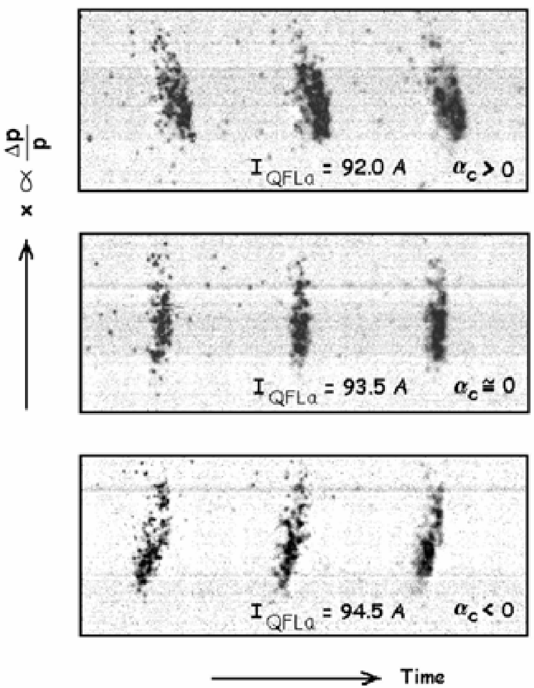

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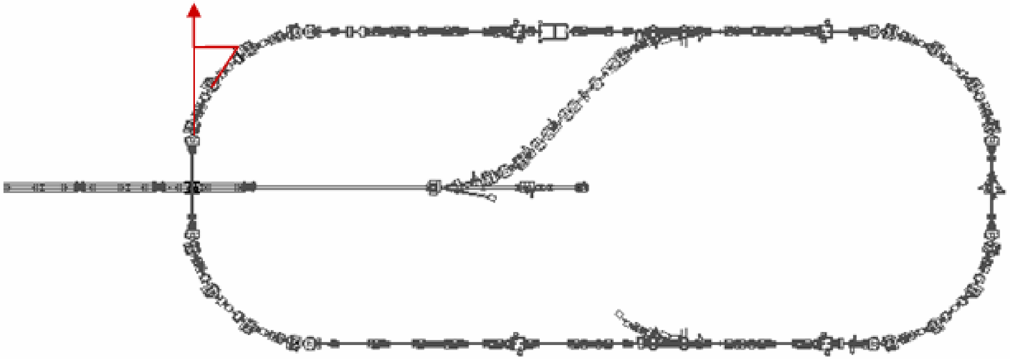
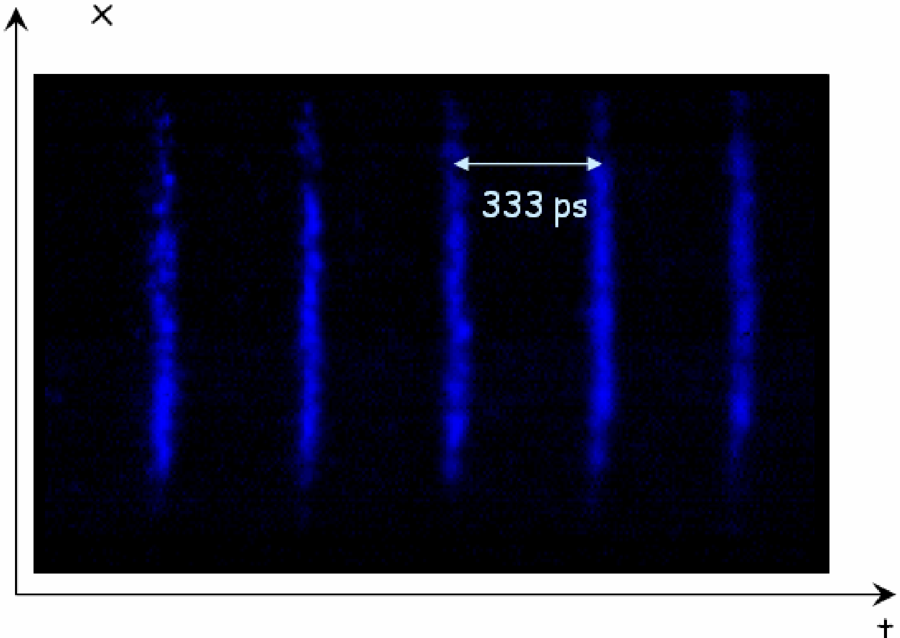
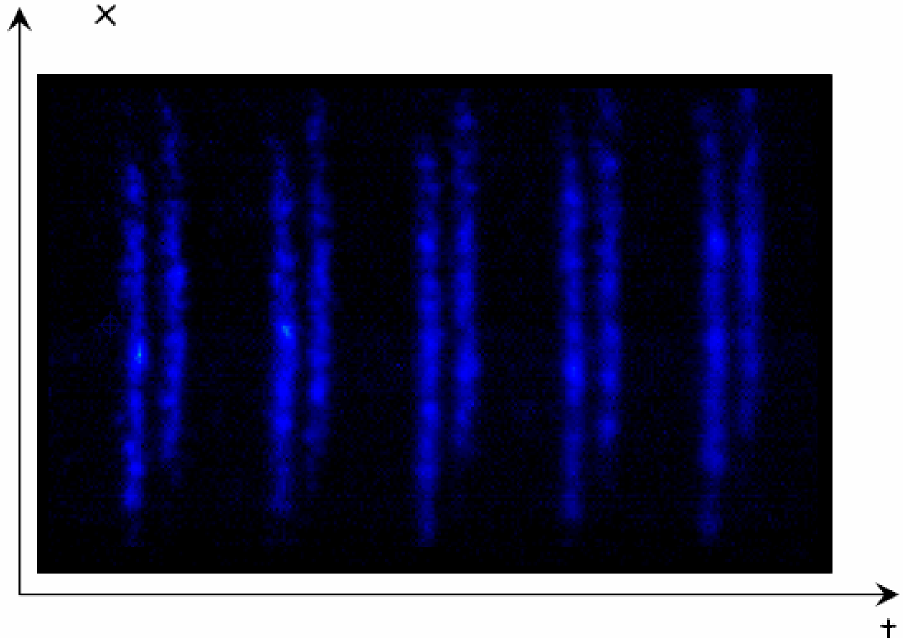


RF injection in combiner ring in CTF3 preliminary phase (2001-2002)



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

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



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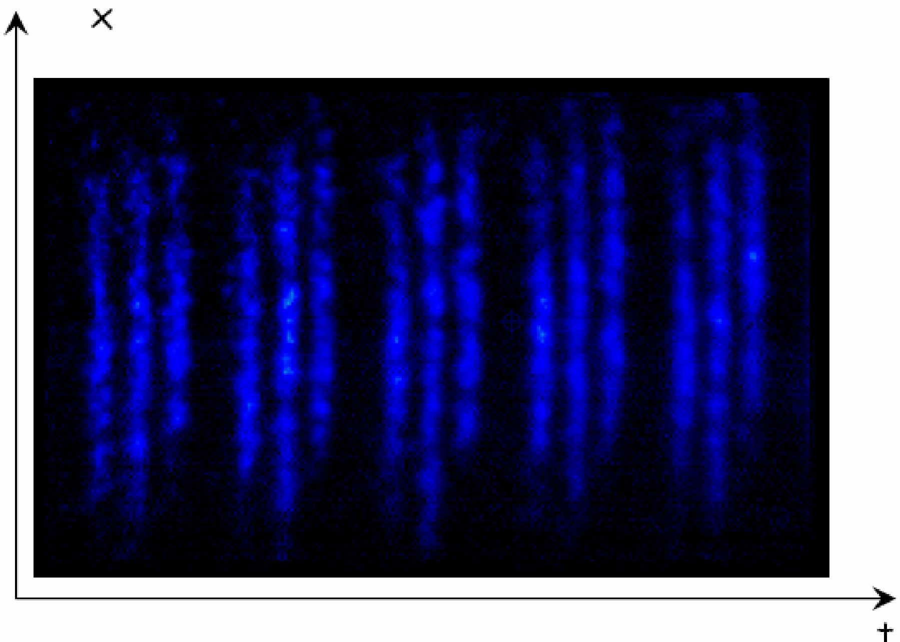

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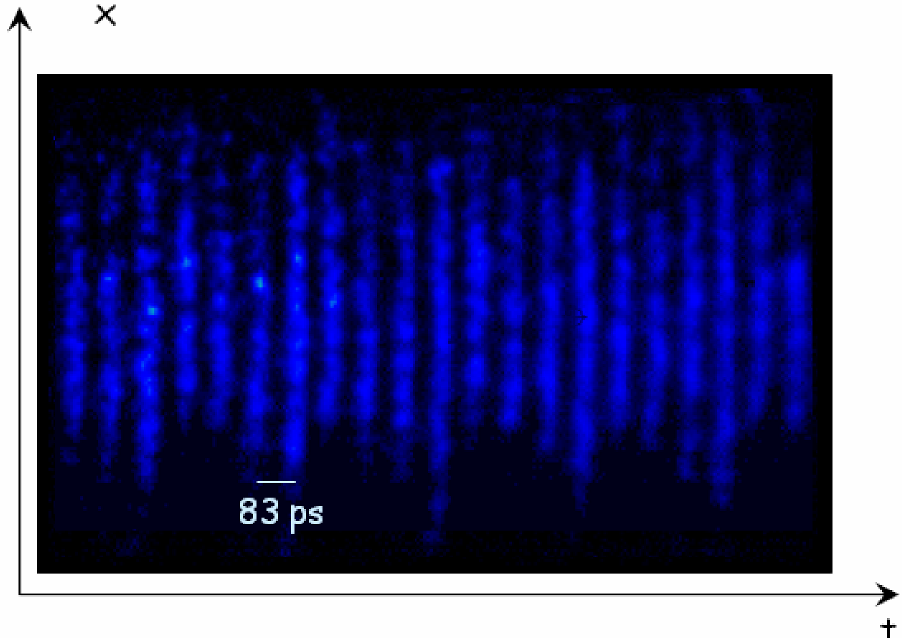
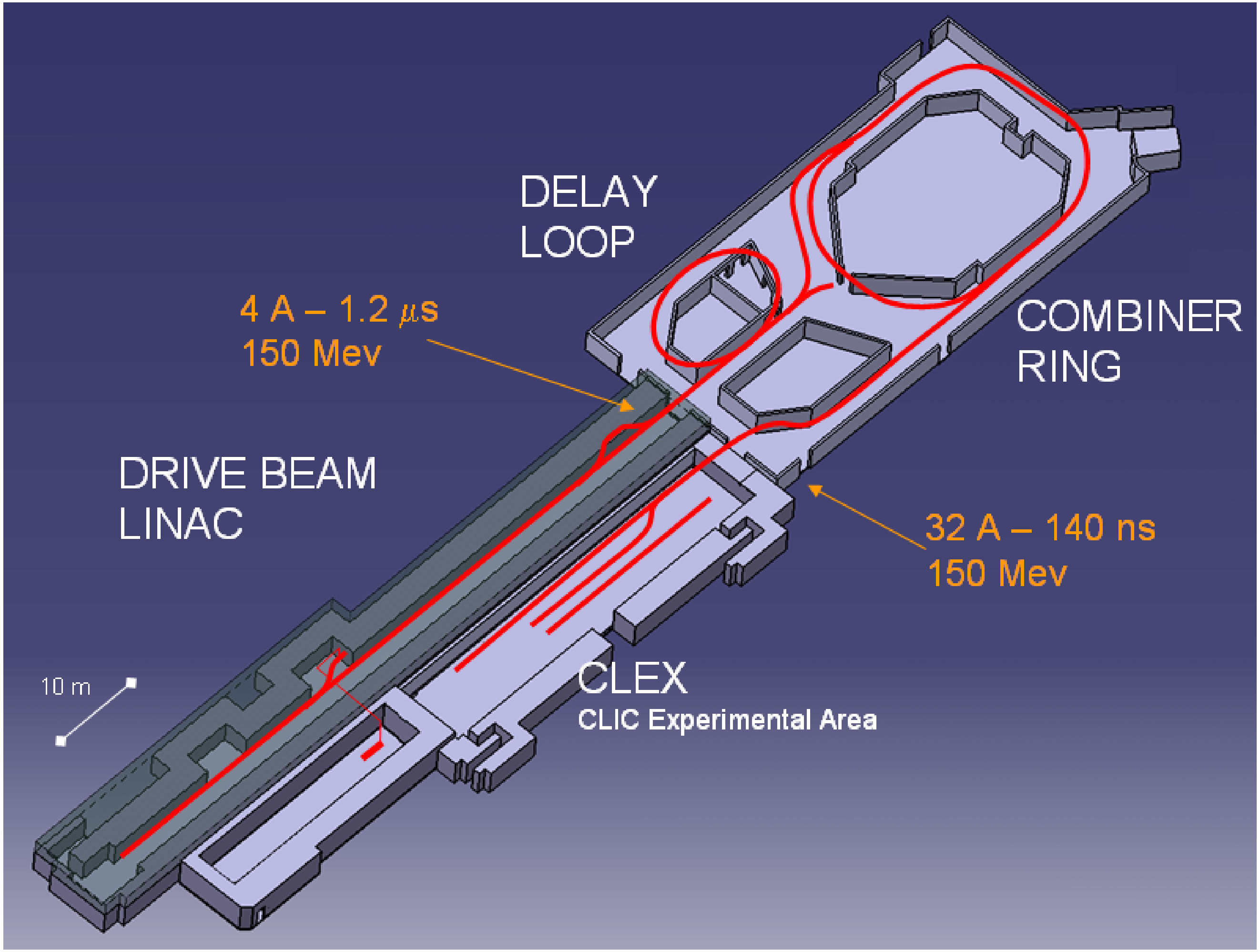


Streak camera images of the beam, showing the bunch combination process

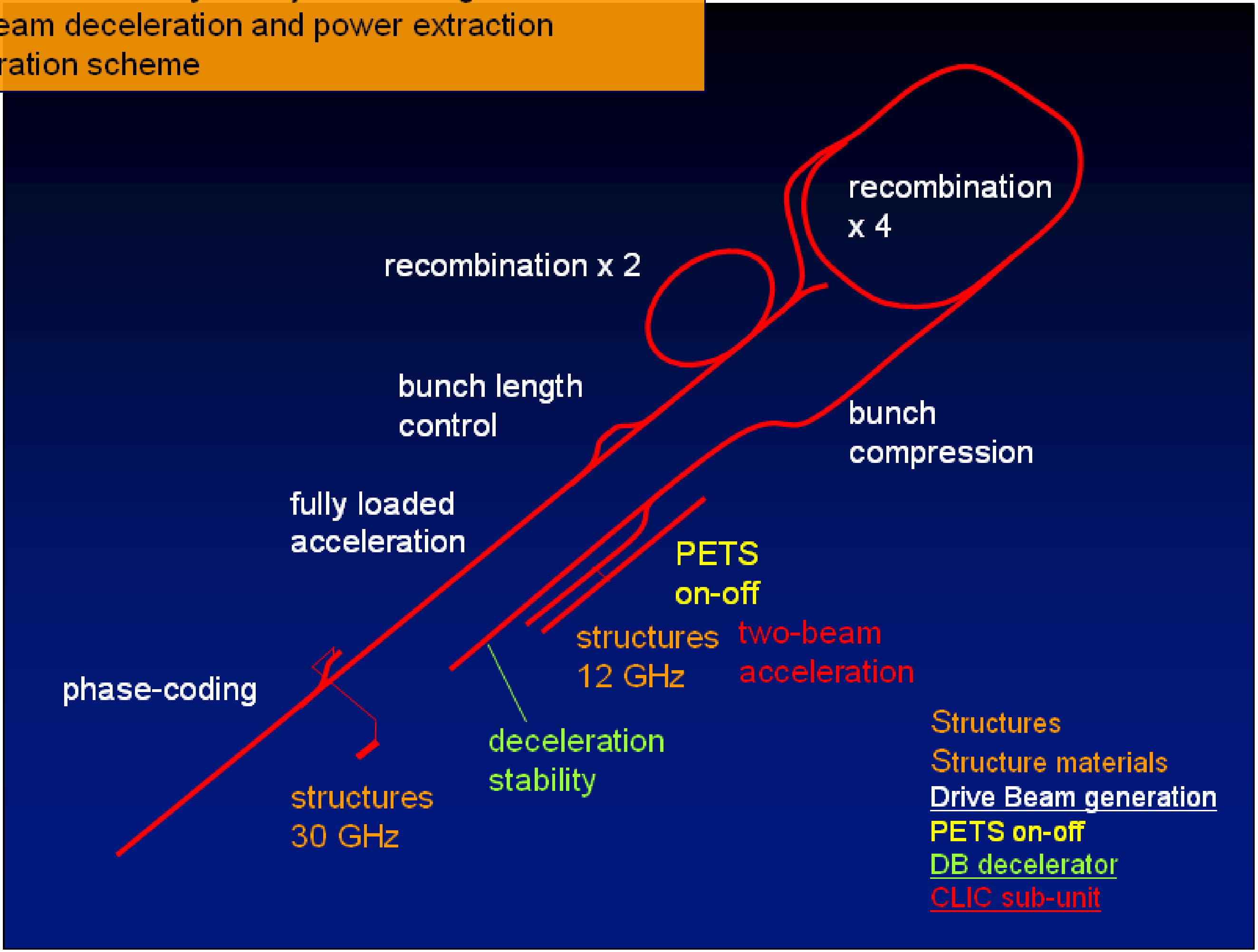
The CLIC Test Facility CTF3

is a small scale version of the CLIC drive beam complex

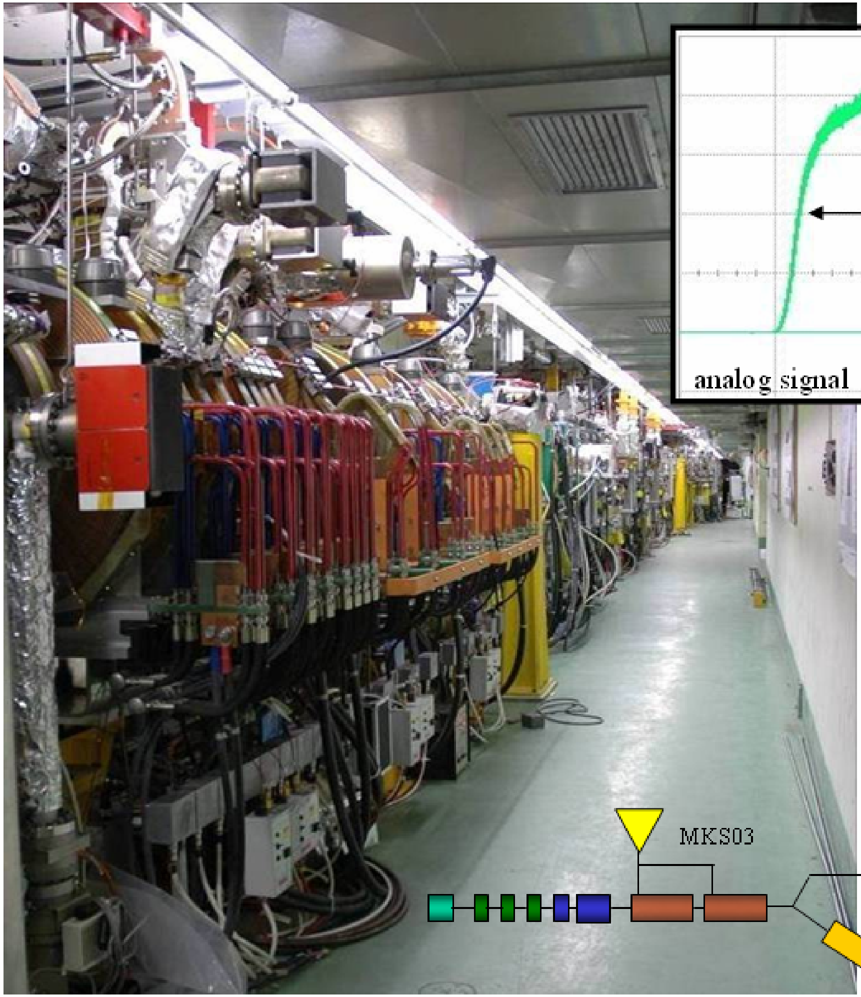


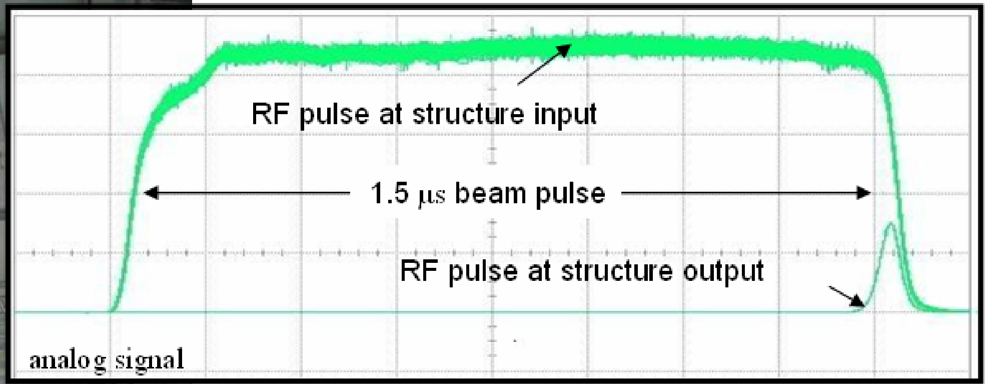
Two Beam Linear Colliders – Special Issues

- ✓ Provide RF power to test accelerating structures and components
- ✓ Full beam-loading accelerator operation
- ✓ Electron beam recombination by RF injection at high current
- ✓ Safe and stable beam deceleration and power extraction
- ✓ Two-beam acceleration scheme



Drive Beam linac – high current, full beam loading operation



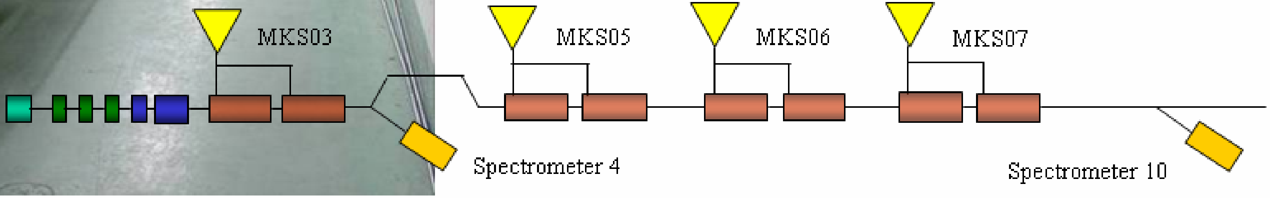


Measured RF-to-beam efficiency

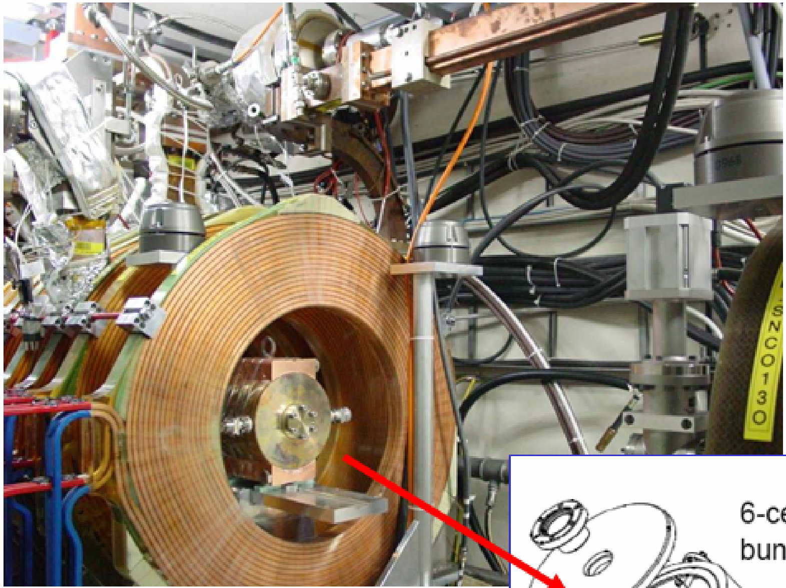
95.3 %

Theory

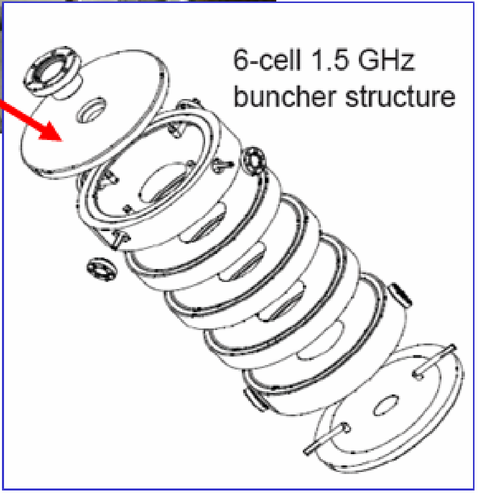
96% (~ 4 % ohmic losses)



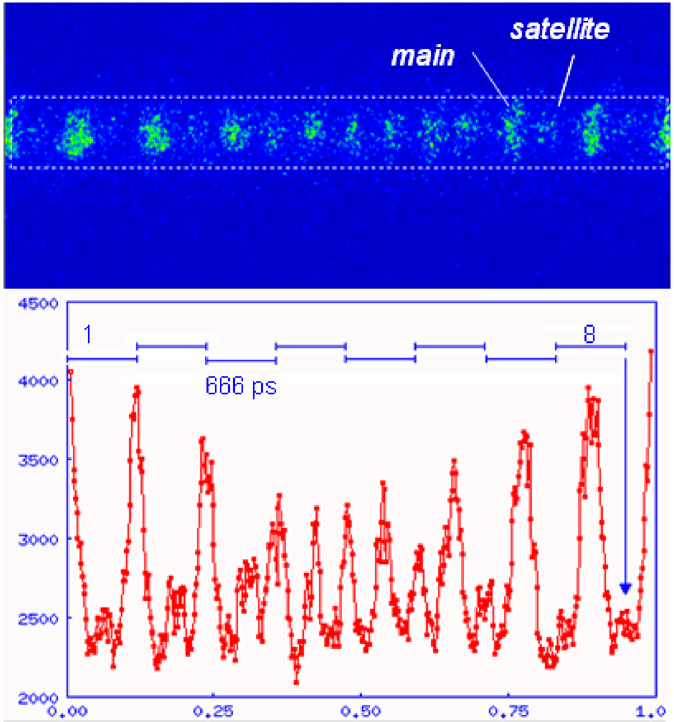
Fast phase switch from SHB system (CTF3)

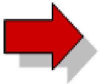


3 TW Sub-harmonic bunchers, each fed by a wide-band TWT



Streak camera image

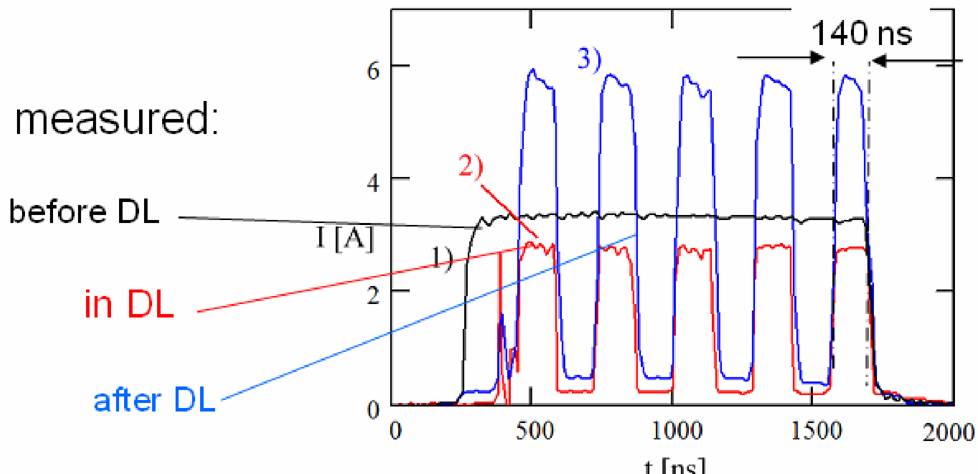


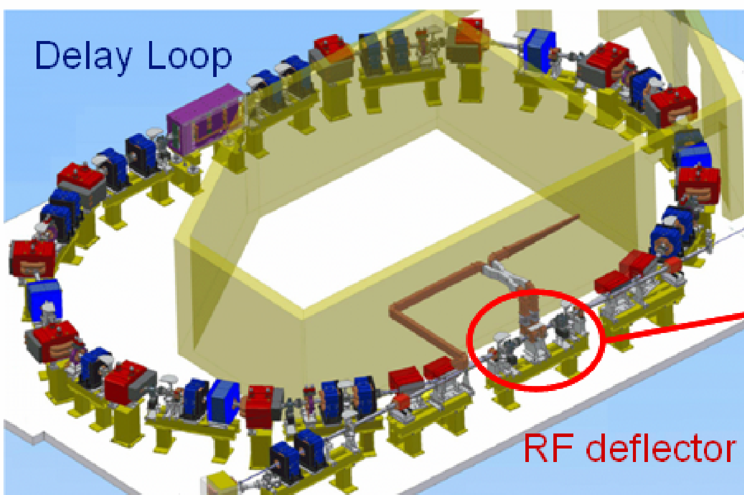


8.5 · 666 ps = 5.7 ns

Delay Loop – beam current multiplication x 2, hole creation

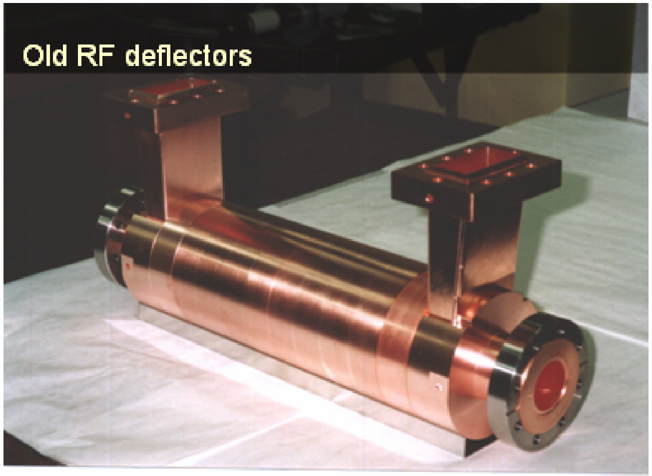
Beam current measured:

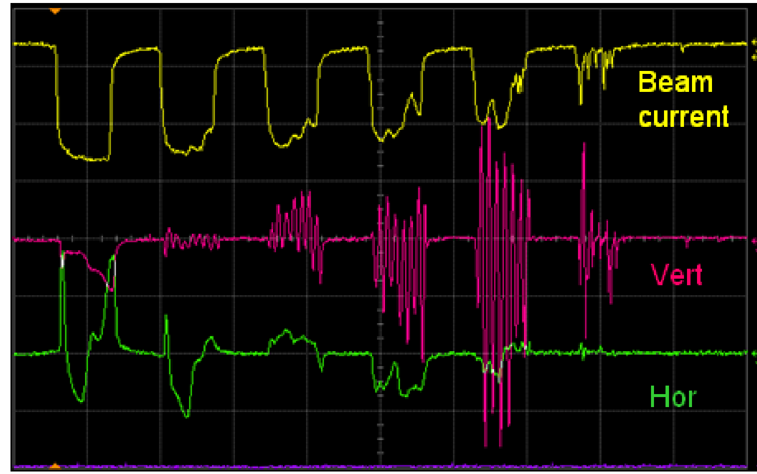




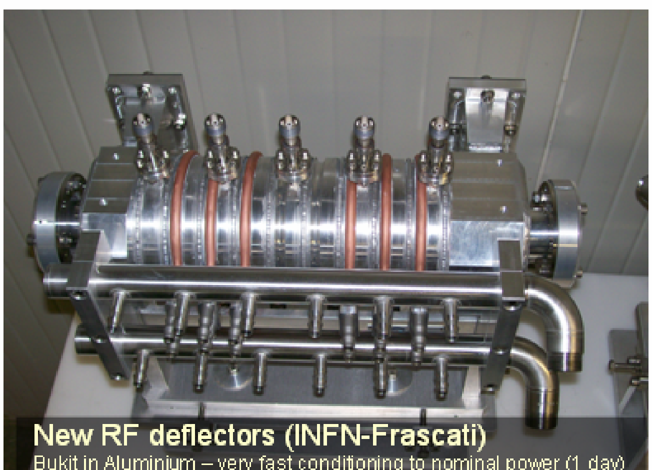
Combiner Ring

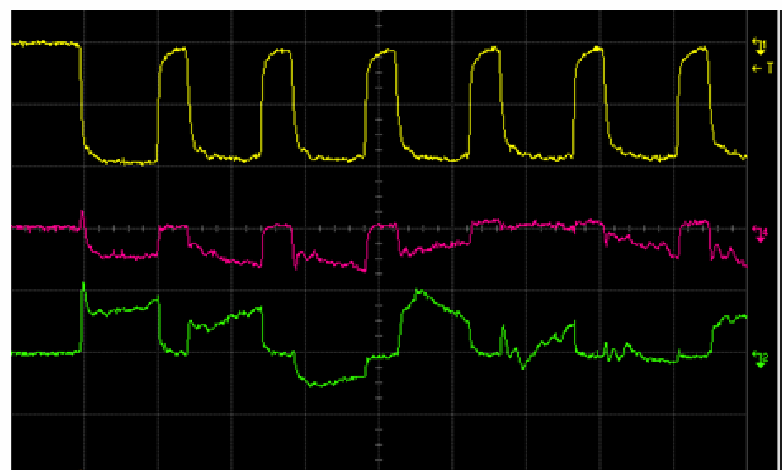
Fast vertical beam instability in CTF3 solved by new deflectors
with strong damping of the vertical deflecting mode and larger hor./vert. detuning

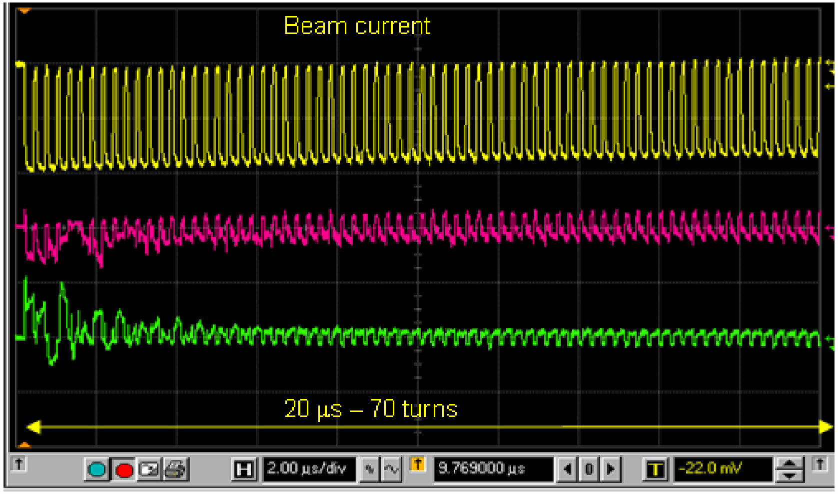

Old RF deflectors



D. Alesini - WE1PBC04


New RF deflectors (INFN-Frascati)
Bukit in Aluminium – very fast conditioning to nominal power (1 day)



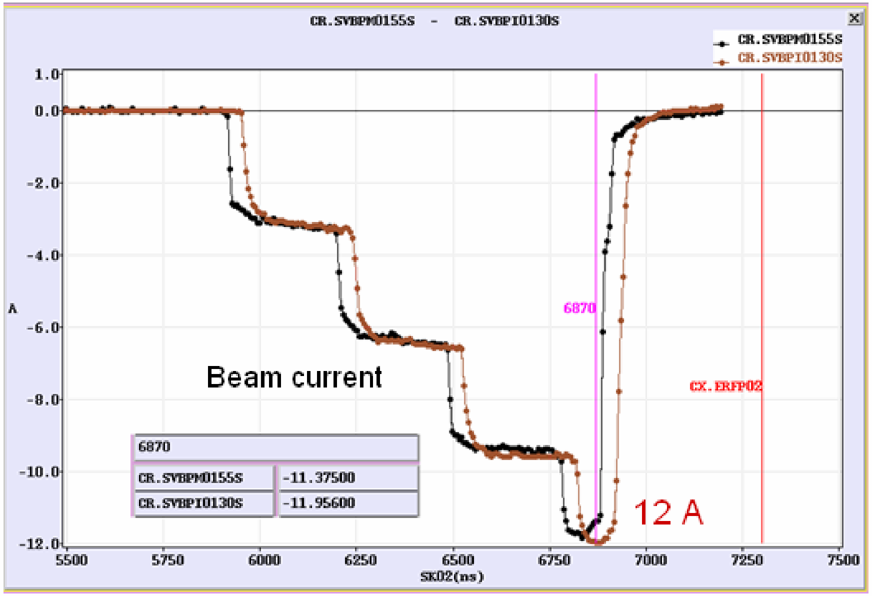


Without the losses from the fast vertical beam instability (plus improved optics control and tuning tools) it is now possible to circulate the 3 A beam with very small losses for hundreds of turns.

Combiner Ring

Bunch re-combination of a 3 A beam with factor four current increase had been demonstrated – 12 A reached.

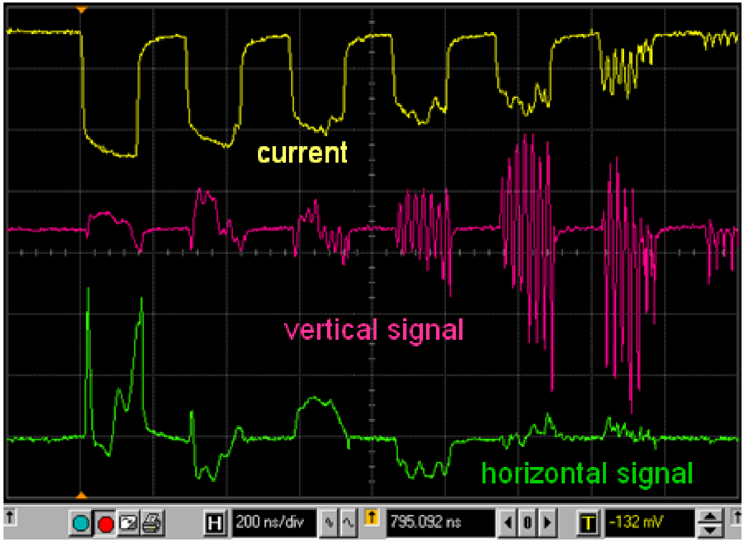
(DL still by-passed, and limited by RF pulse length)



Learning in CTF3: procedures, measurements etc..

CTF3 is a test facility, we assume its main goal is to provide a convincing demonstration of the CLIC technology, BUT possibly *even more important* is use it to

- Identify potential problems



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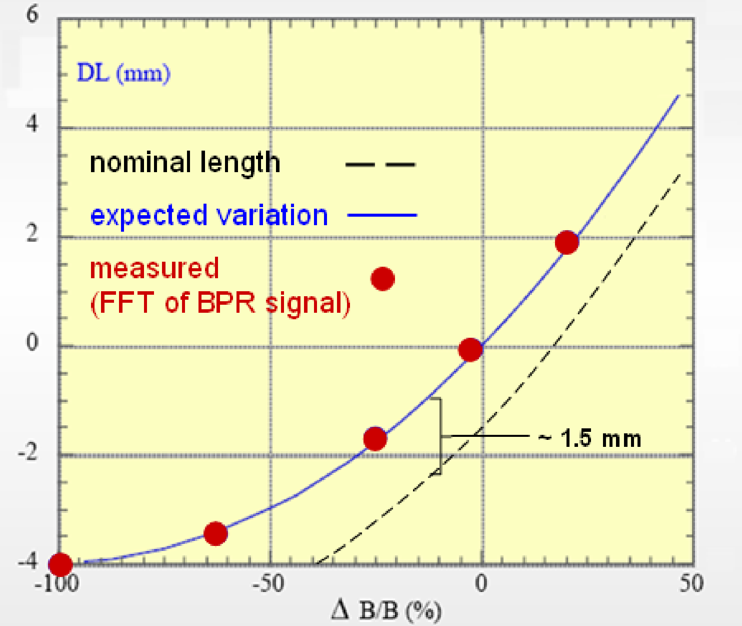
- Develop measurement devices & methods



Path length variation as a function of wiggler field

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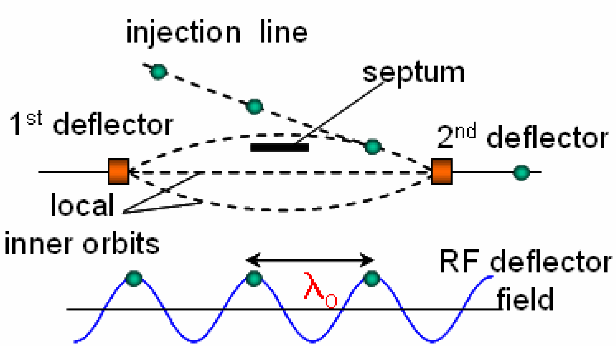
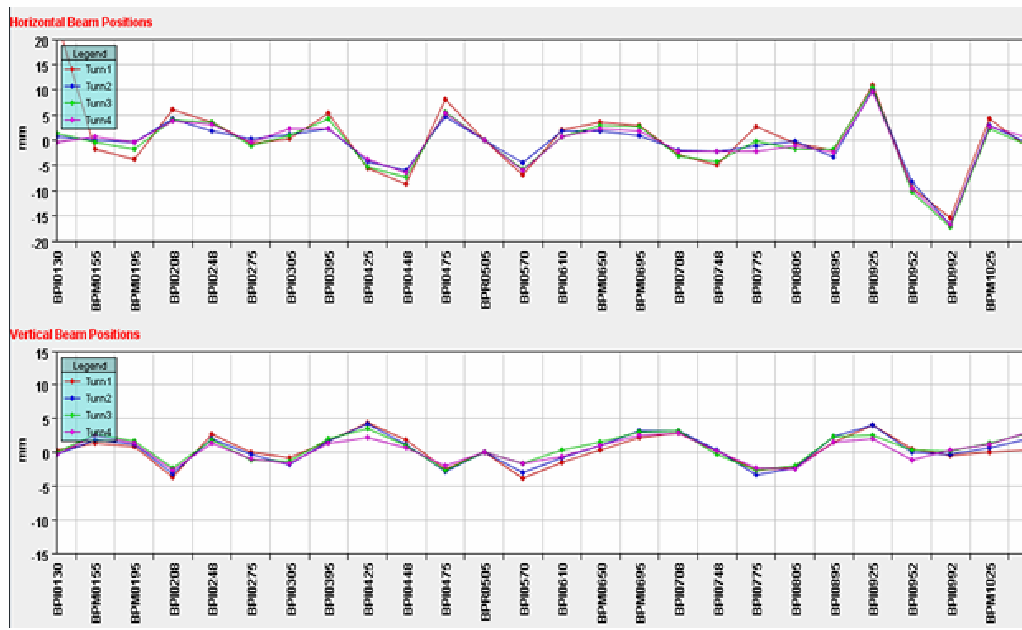
- Develop beam tuning procedures





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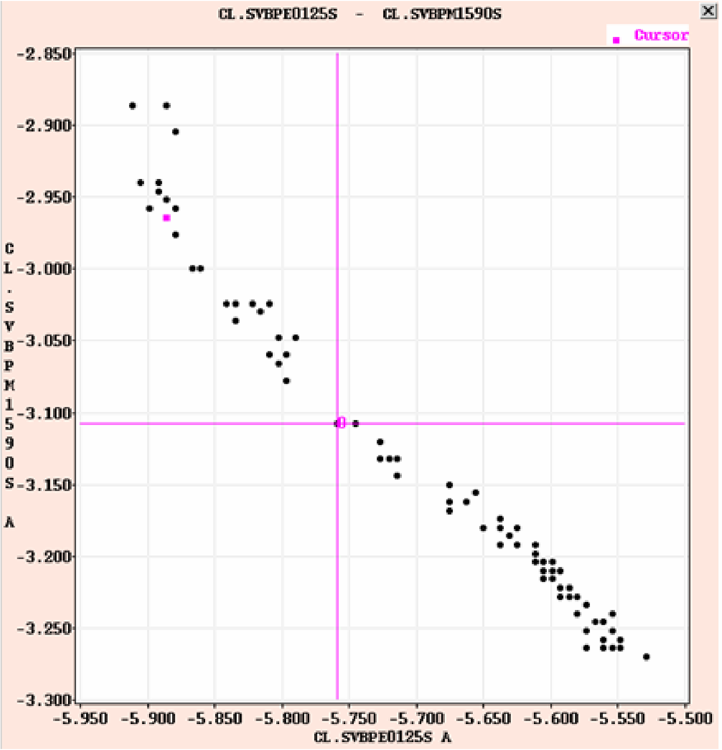
- Develop measurement devices & methods
- Develop beam tuning procedures
- Test feedback & stabilization techniques



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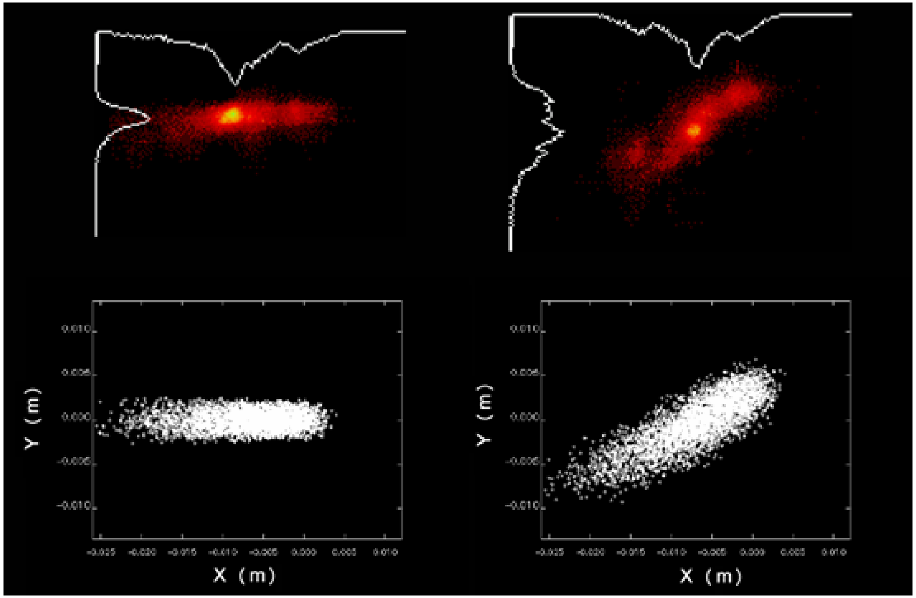
- Identify potential problems
- Develop measurement devices & methods
- Develop beam tuning procedures
- Test feedback & stabilization techniques
- Benchmark simulations



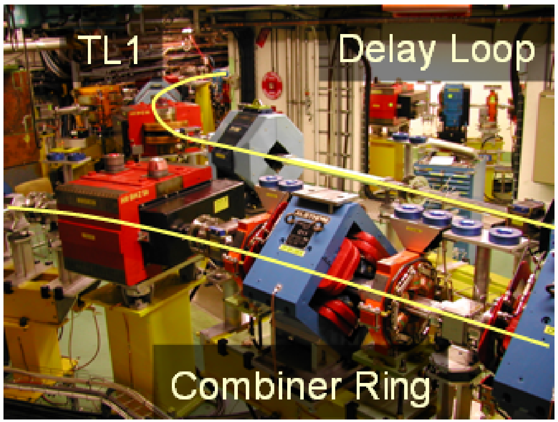
Two Beam Linear Colliders – Special Issues

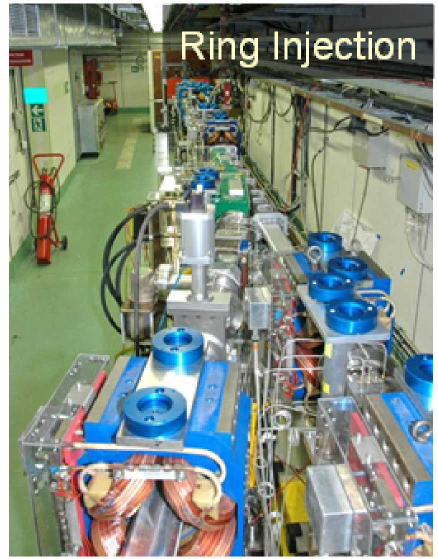
R. Corsini, 8.5.2009

Transfer lines and CLEX

Most of the hardware has now been installed !

Ring Area

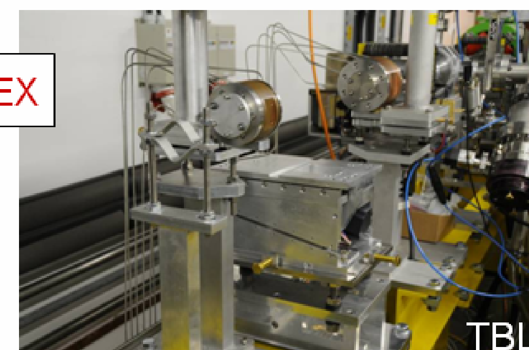




V.C. Sahni - TH1GRI04

CLEX

C. Simon - TH5RFP024

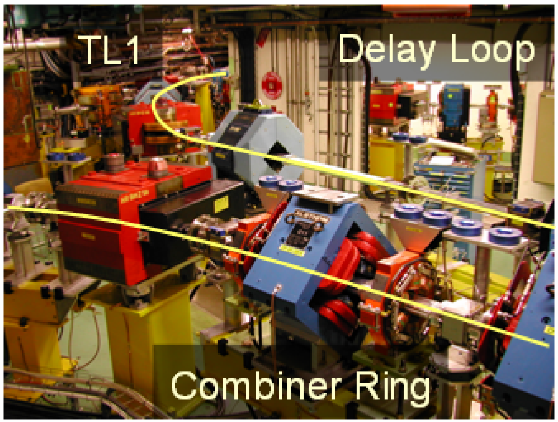


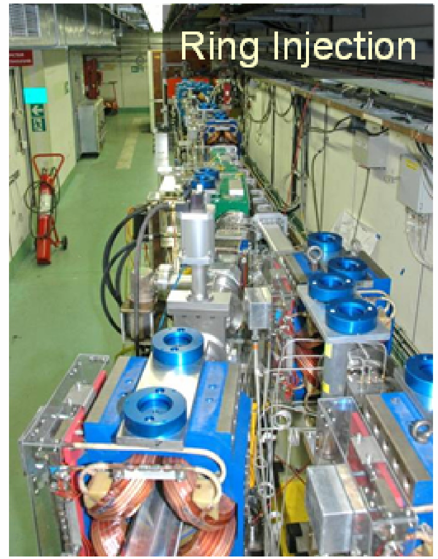
A. Faus-Golfe - TH5RFP054

Transfer lines and CLEX

Most of the hardware has now been installed !

Ring Area





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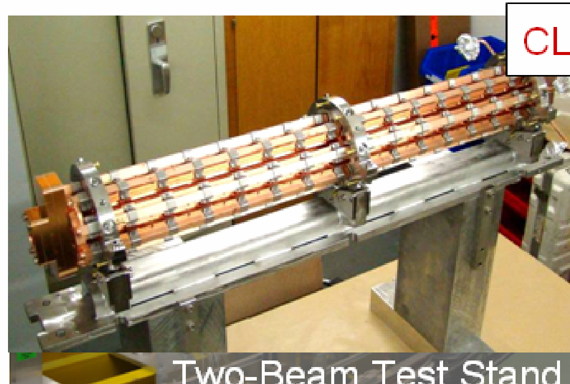
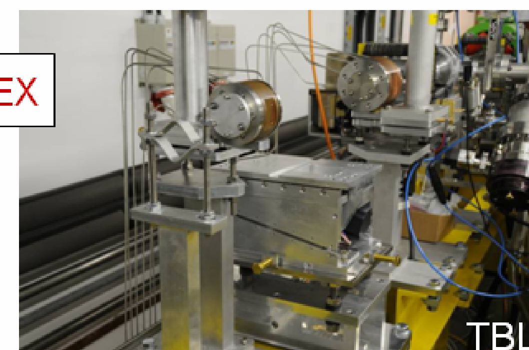
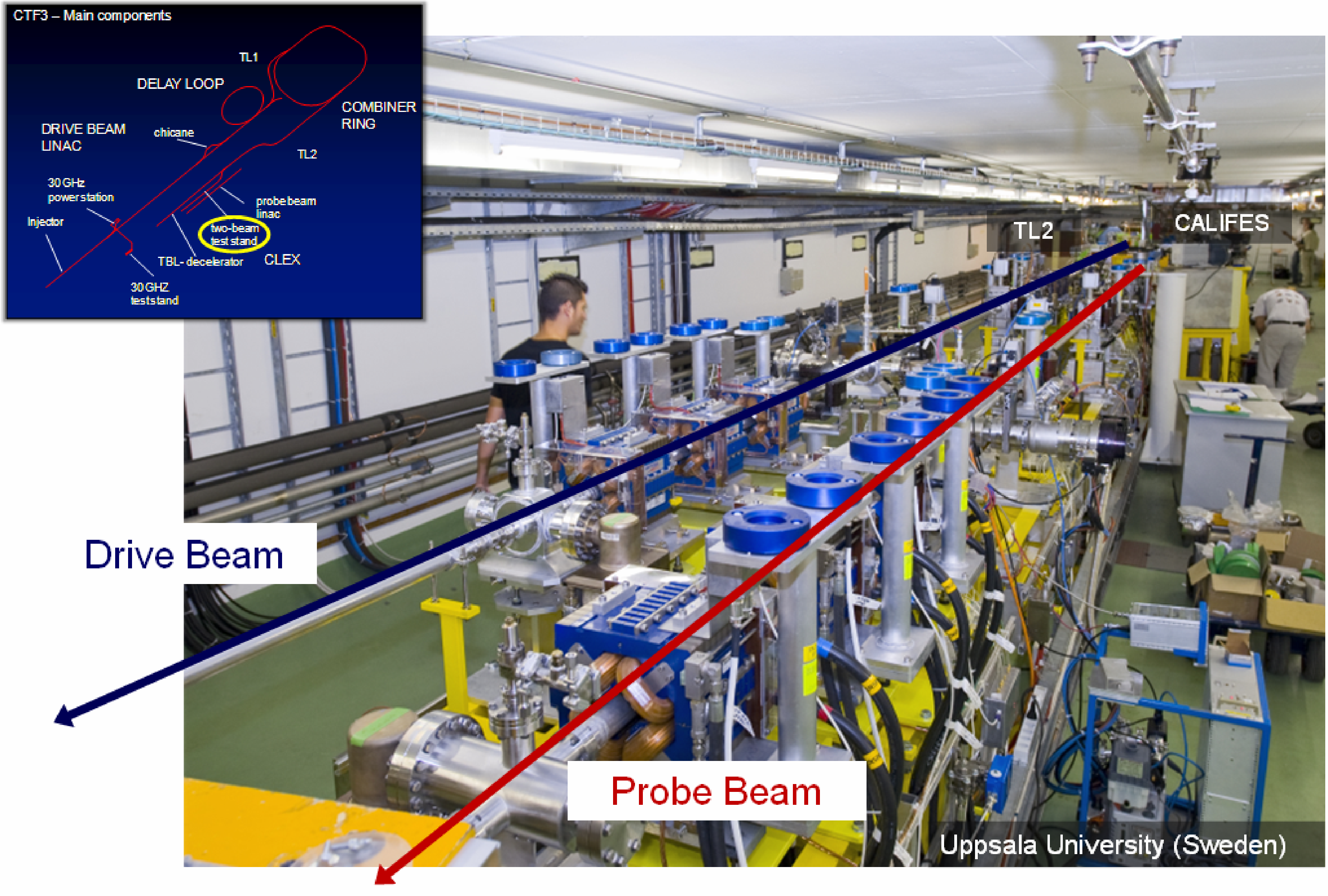


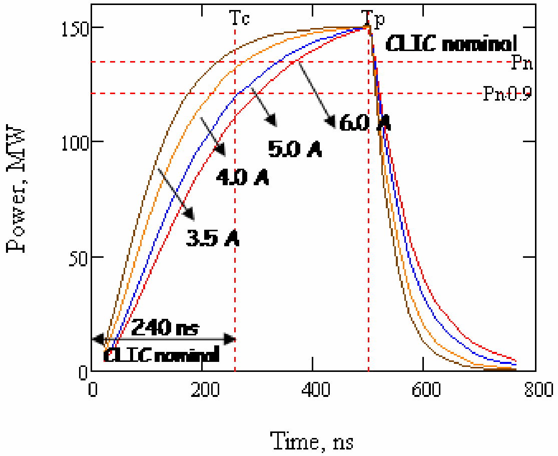


A. Faus-Golfe - TH5RFP054

Two Beam Linear Colliders – Special Issues

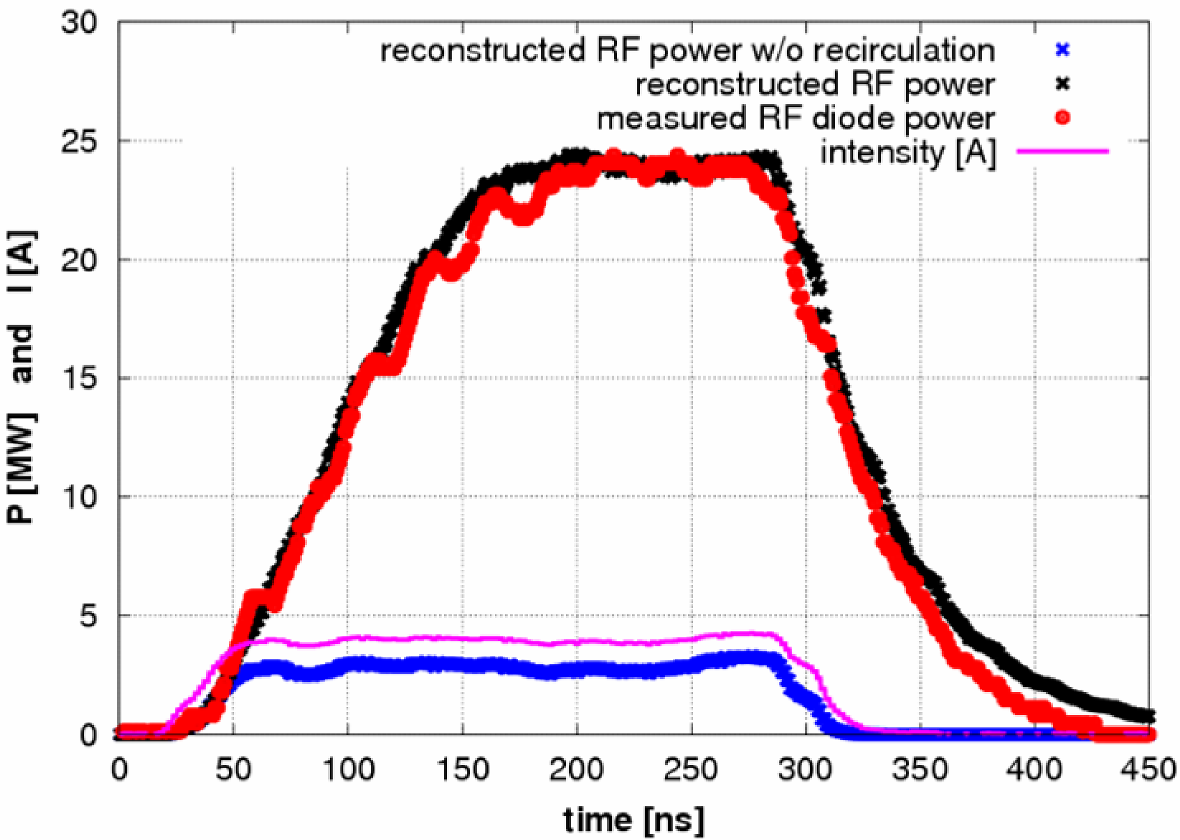


First power production from 12 GHz PETS



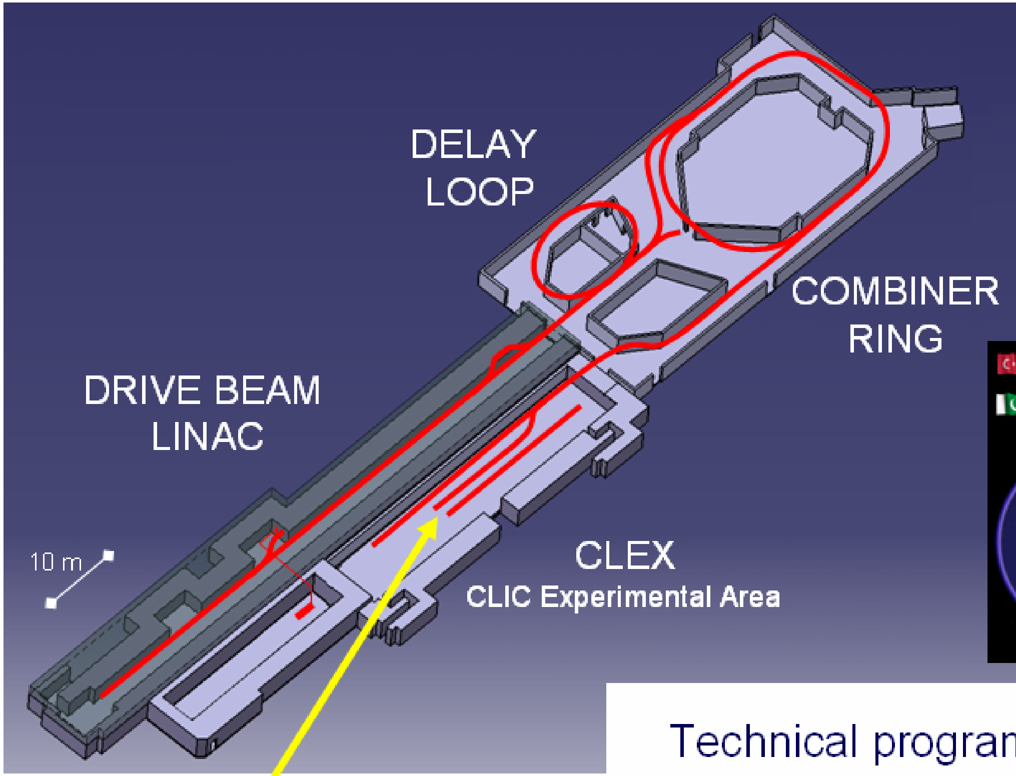
Re-circulation

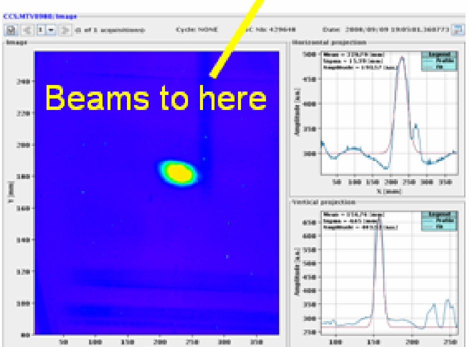
First power production from 12 GHz PETS



I. Syratchev - WE3RAC02

Re-circulation





CTF3 Status

Progress possible through successful collaboration between 28 international institutes

Technical programme is on track

- CTF3 on schedule

  full beam loading

  bunch phase coding and Delay Loop operation

  First results on recombination in Combiner Ring

All machine components installed - apart from TBL

Next Steps in CTF3

- TBL drive beam deceleration studies (string ofup to 16 PETS)
- Study of two-beam issues
  - RF breakdown kicks experiment
  - Beam loading compensation of probe beam

2010

- Photo-injector option full implementation
- Phase stability measurements & feed-forward tests
- CTF3 upgraded to X-band power production & testing facility
- Full-fledged CLIC modules beam tests in CLEX
- Instrumentation development for LC – Instrumentation Test Beamline

2012 +

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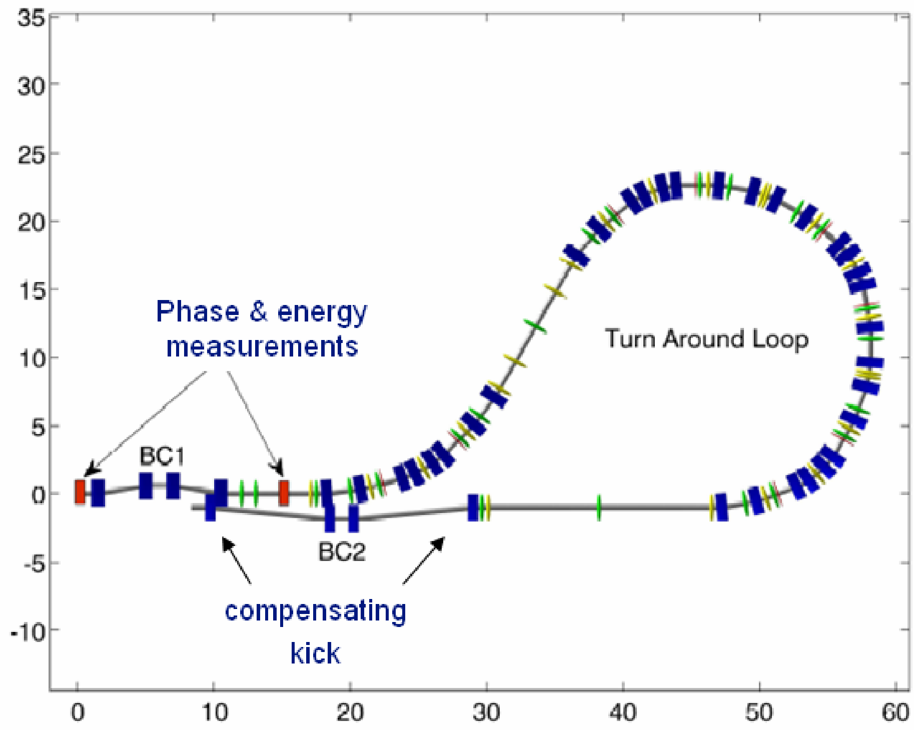
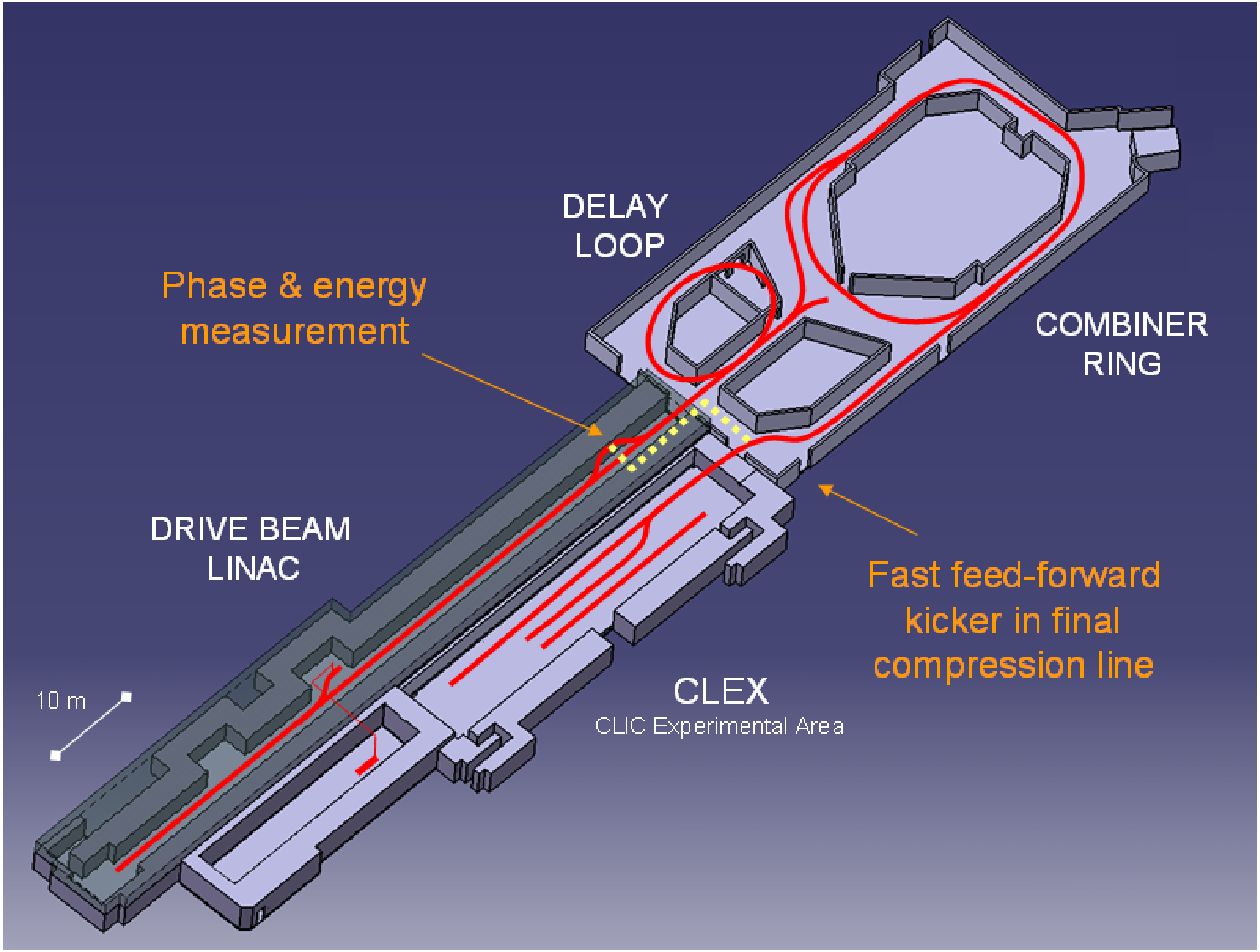
2012 +

Phase stability measurements & feed-forward

0.2 degrees phase stability @ 12 GHz required for CLIC drive beam for 2% luminosity loss

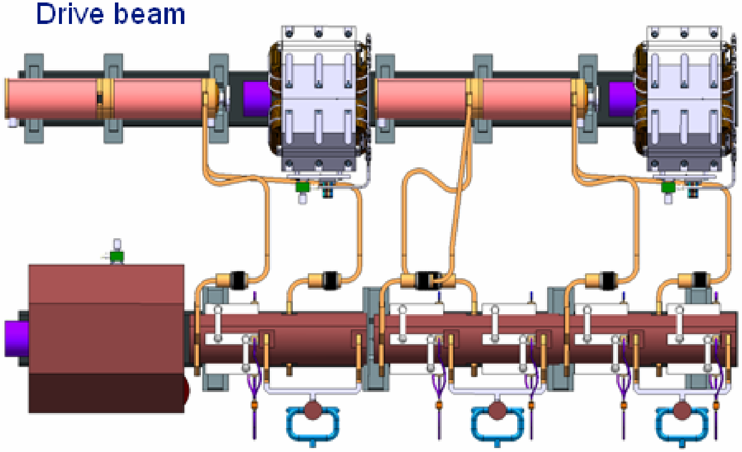


Phase stability measurements & feed-forward



Two-beam modules in TBTS

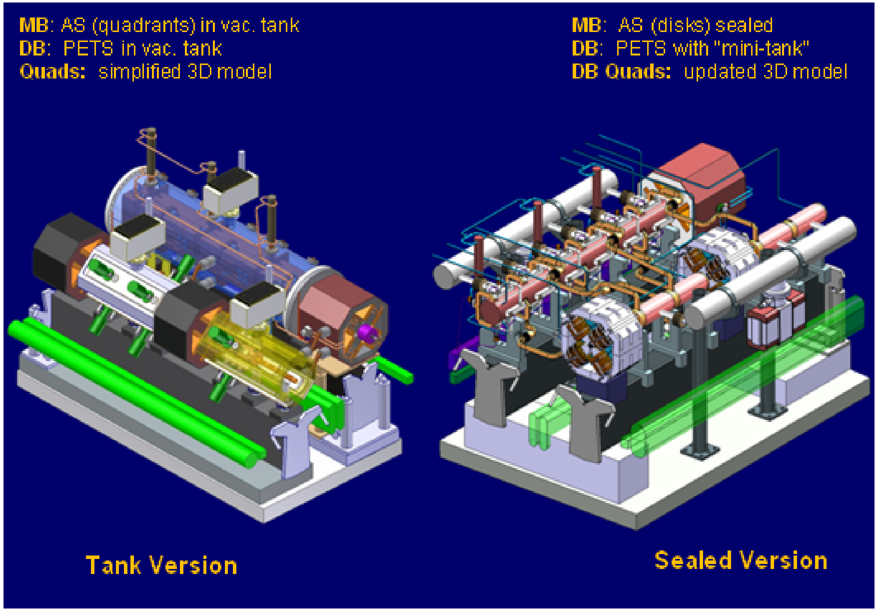
- Module design and integration have to be studied for different configurations.
- Integration of the systems in terms of space reservation has been done. Detailed design started for the main systems, such vacuum, cooling, alignment, stabilisation …
- Important aspects for cost and basic parameters provided for other areas of the study.



20760 modules (2 m long)

71460 power prod. structures PETS (drive beam)

143010 accelerating structures (main beam)



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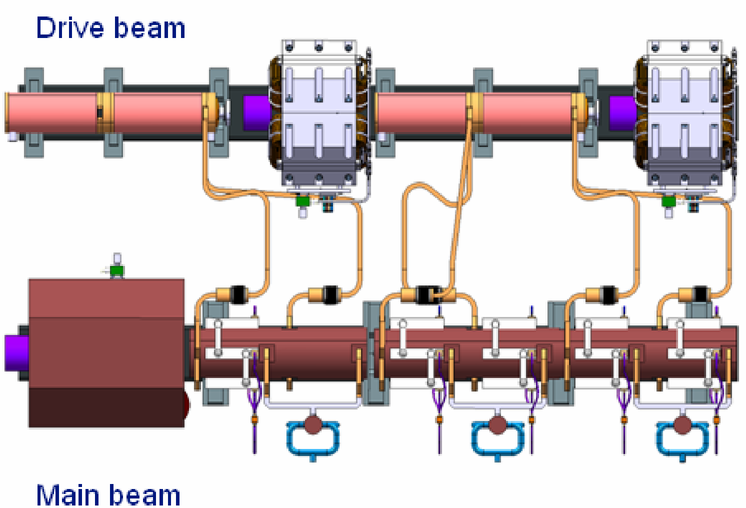
- Integration of the systems in terms of space reservation has been done. Detailed design started for the main systems, such vacuum, cooling, alignment, stabilisation …
- Important aspects for cost and basic parameters provided for other areas of the study.
- Goal: build prototype → test with beam of a few modules in CTF3 from 2010



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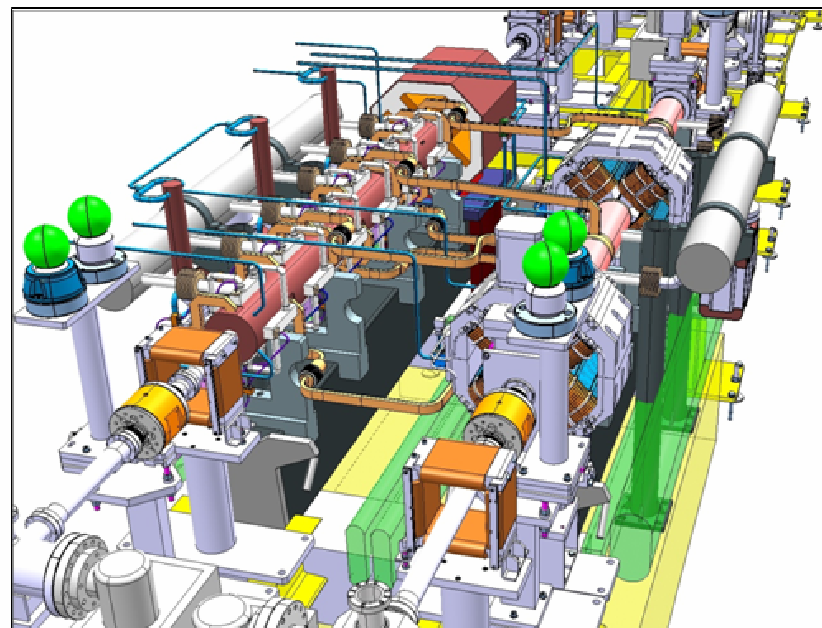
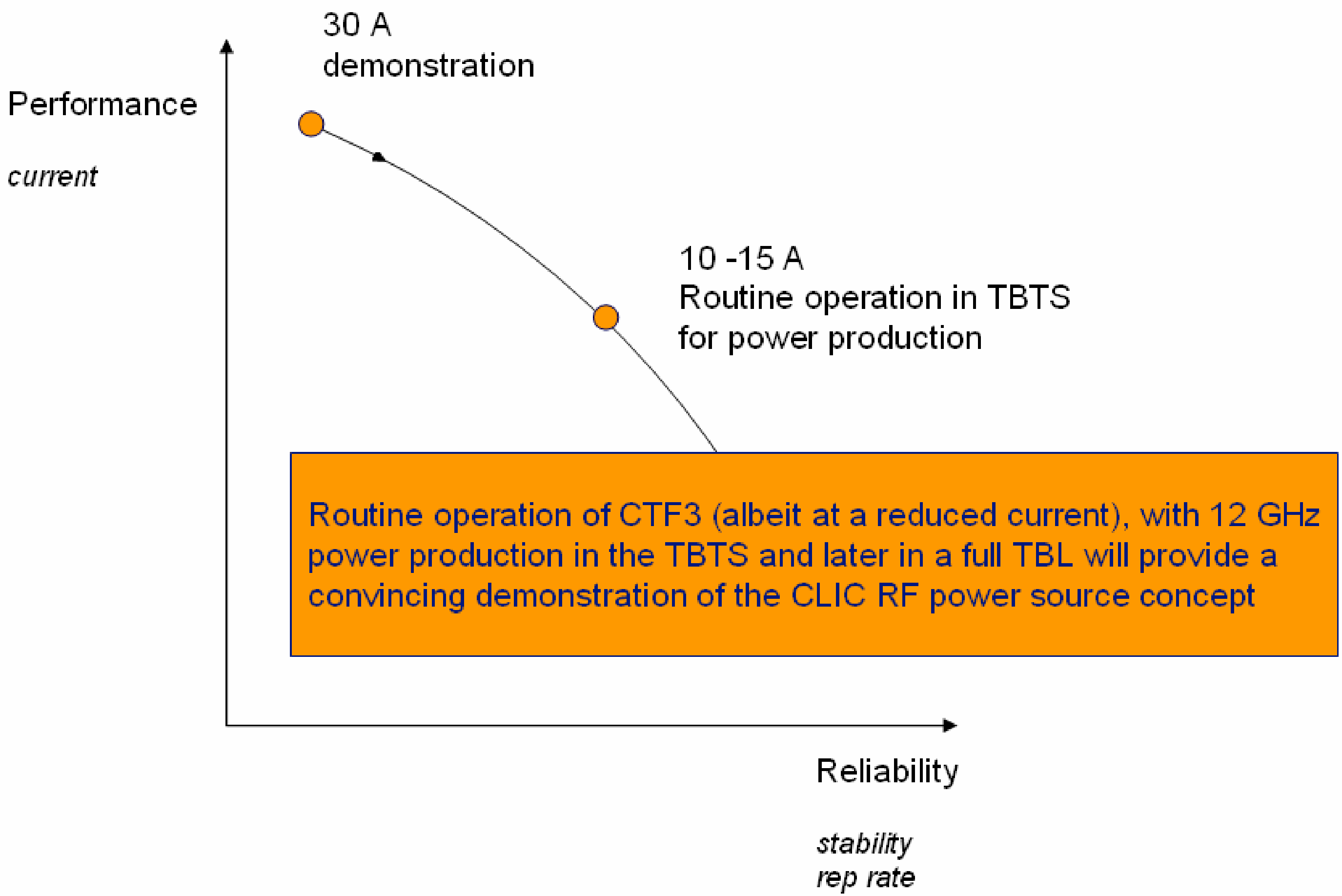


Conclusions

- The CLIC TBA scheme, coupling high-gradient acceleration and efficiency, evolved during the years, as ideas and techniques were devised and tested.
- The scheme basics were virtually untouched in the last few years as the concept reached maturity.
- The CTF3 facility is the main tool to demonstrate the scheme feasibility. A number of issues were already addressed, such as isochronicity, full beam loading operation, bunch phase coding, path length control and the interleaving scheme.
- CTF3 commissioning is being completed and a full current combination test is expected in 2009.
- The next major step, to be completed by 2010, is the study of drive beam deceleration in a string of PETS in the TBL line, presently under installation.
- Future short term studies include an assessment of the drive beam stability, both in current and phase, and the identification of the main sources of jitter.
- In the longer term other experimental tests are under evaluation, including the construction and use of a series of full-fledged CLIC TBA modules and the implementation of a fast phase feed-back system to test the very tight phase stability requirements of the CLIC drive beam (0.2° at 12 GHz)

Performance vs reliability in CTF3



Work Plan until 2010:

- Demonstrate feasibility of CLIC technology (R&D on critical feasibility issues)
- Design of a linear Collider based on CLIC technology
  http://clic-study.web.cern.ch/CLIC-Study/Design.htm
- Estimation of its cost (capital investment & operation)
- CLIC Physics study and detector development
  http://clic-meeting.web.cern.ch/clic-meeting/CLIC_Phy_Study_Website/default.html

Conceptual Design Report to be published in 2010 including:

- Physics, Accelerator and Detectors
- Results of feasibility study
- Preliminary performance and cost estimation

R&D Issues classified in three categories:

- critical for feasibility → fully addressed by specific R&D to be completed before 2010
  results in CDR
- critical for performance
- critical for cost

→ being addressed now by specific R&D to be completed before 2015
first assessments in CDR
results in Technical Design Report (TDR) with consolidated performance & cost

Tentative long-term CLIC scenario

Shortest, Success Oriented, Technically Limited Schedule

Technology evaluation and Physics assessment based on LHC results
for a possible decision on Linear Collider with staged construction starting with the lowest energy required by Physics

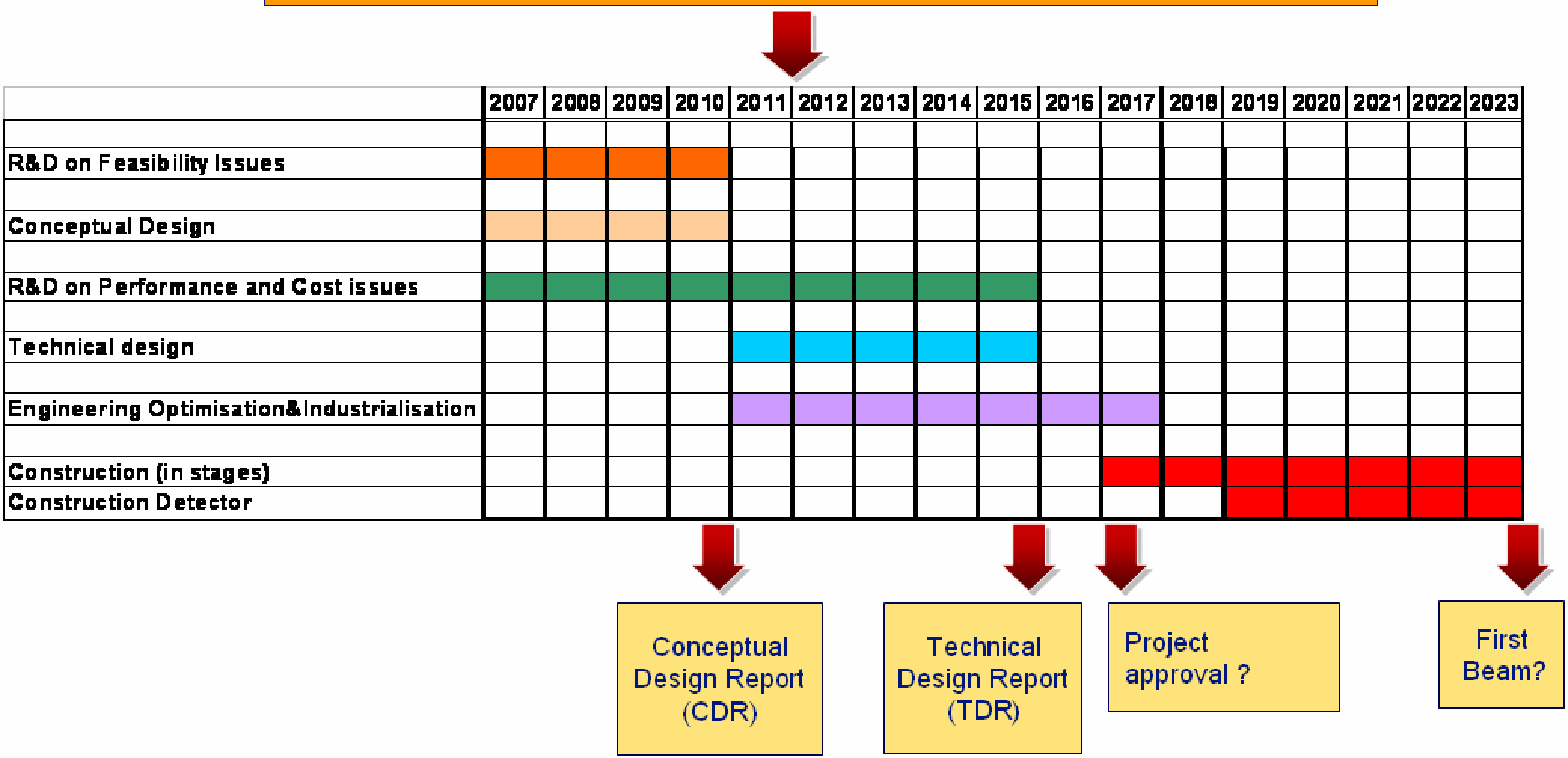
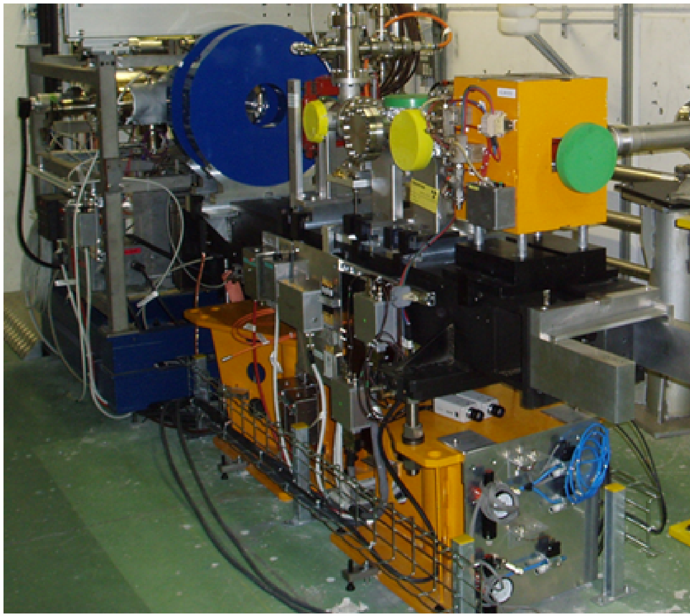
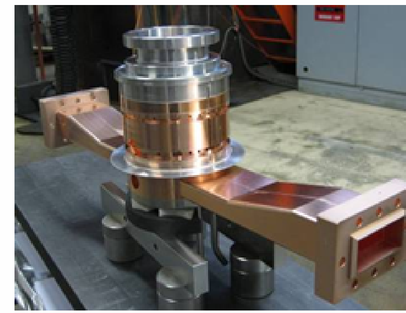
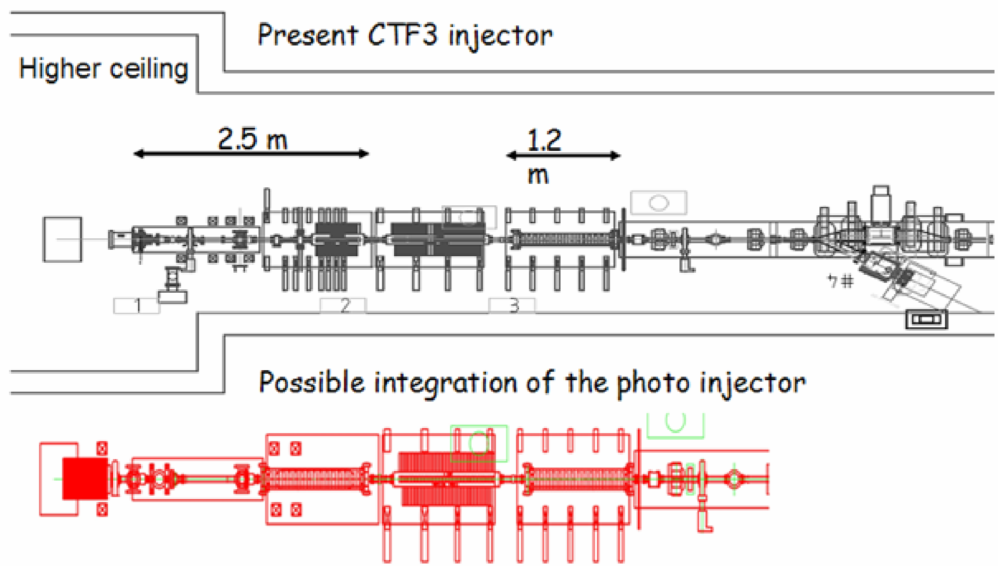


Photo-injector option full implementation







- Smaller transverse emittance
- Shorter bunches, no energy tails
- No satellites
- Lower current

Single bunch option will allow

- Check and correction of beam optics with high precision
- CSR measurements with high precision in DL, CR and TL2 bunch compressor.
- δ response of PETS and beam instrumentation
- ...

Two Beam Linear Colliders – Special Issues

Parameter	Unit	CLIC nominal	Present state of the art	Objective 2010	Objective 2012
I initial	A	7	5	5	5
I final	A	100	12	30	30
Qb	nC	8.4	4	2.3	2.3
Emittance, norm rms	π mm mrad	≤ 150	100 (end of linac)	≤ 150 (comb. beam)	≤ 150 (comb. beam)
Bunch length	mm	≤ 1	≤ 1 (end of linac)	≤ 1 (comb. beam)	≤ 1 (comb. beam)
E	GeV	2.4	120	120	150
T_{pulse} initial	μs	140	1.4	1.4	1.4
T_{pulse} final	ns	240	140 (240)	140 (240)	140 (240)
Beam Load. Eff.	%	97	95	95	95
Deceleration	%	90	-	50	50
Phase stability @ 12 GHz	degrees	0.2	-		
Intensity stability		10^{-5}	10^{-3}		