

CLIC = Compact Linear Collider



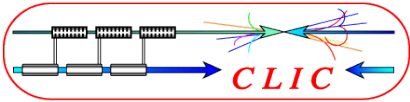
The CLIC study for a future $e^+ e^-$ linear collider

Louis Rinolfi / CERN



CTF3





A very short history for CLIC



Almost 25 years !!!

1985: **CLIC = CERN Linear Collider**

CLIC Note 1: “Some implications for future accelerators” by J.D. Lawson => first CLIC Note

1995: **CLIC = Compact Linear Collider**

➤ 7 Linear colliders studies (TESLA, SBLC, JLC_C, JLC_X, NLC, VLEPP, CLIC)

2004: **International Technology Recommendation Panel selects the Superconducting RF technology (TESLA based) versus room temperature copper structures (JLC/NLC based)**

=> International Linear Collider study (ILC) at 1.3 GHz for the TeV scale

CLIC study at 30 GHz continues for the multi-TeV scale

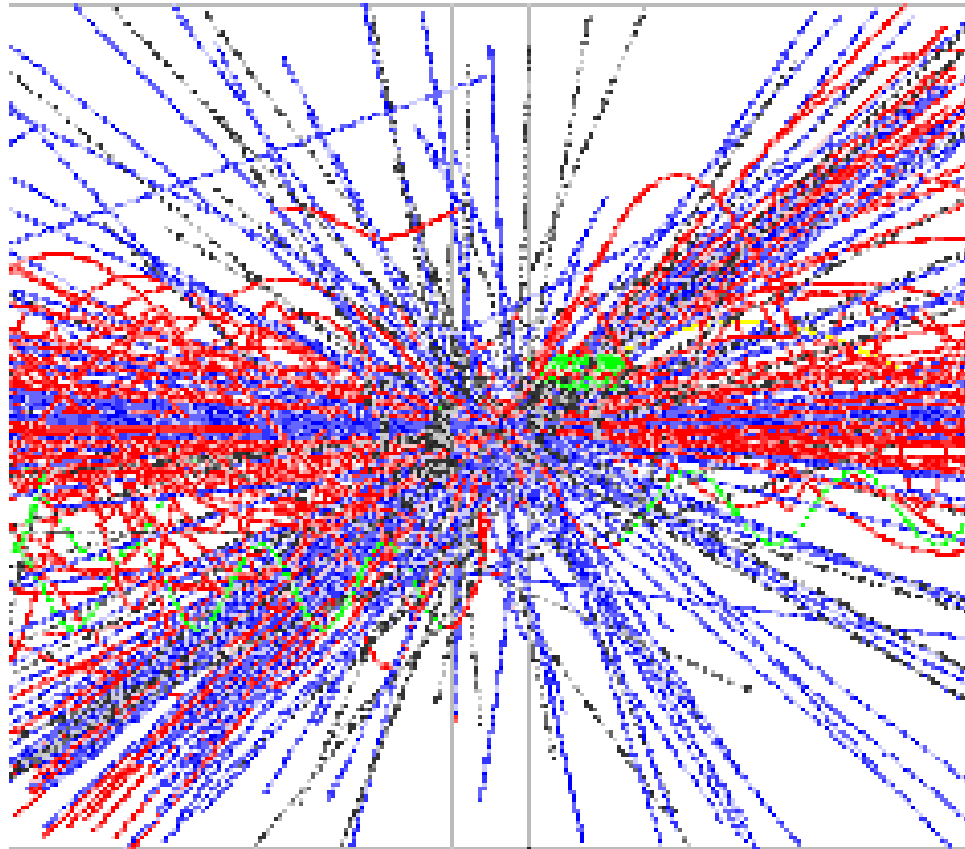
2006: **CERN council Strategy group (Lisbon July 2006) => “... a coordinated programme should be intensified to develop the CLIC technology ... for future accelerators....”**

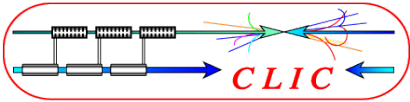
2007: **Major parameters changes: 30 GHz => 12 GHz and 150 MV/m => 100 MV/m**
First CLIC workshop in October

2008: **Successful test of a CLIC structure @ 12GHz** (designed @cern, built @kek, RF tested @slac)

2009: **Preparation of the Conceptual Design Report (CDR) for the end of 2010**

The Physics in the multi-TeV energy range





LHC expectation:

LHC will indicate what physics should be investigated and at what energy scale:

is 500 GeV (c.m.) enough ? Do we need multi-TeV energy ?

LHC results would establish the scientific case for a Linear Collider

CLIC expectation:

CLIC nominal energy study is 3 TeV.

However the present design is done in order to run over a wide energy range: 0.5 to 3 TeV (studies have been performed up to 5 TeV).

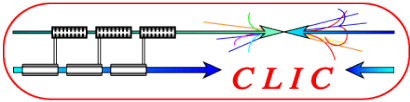
<http://clic-study.web.cern.ch/CLIC-Study/Design.htm>

Physics motivation:

"Physics at the CLIC Multi-TeV Linear Collider":

report of the CLIC Physics Working Group, CERN report 2004-5

http://clic-meeting.web.cern.ch/clic-meeting/CLIC_Phy_Study_Website/default.html



K. Peach / JAI

Last week at the
CLIC09 workshop

5 good arguments for 2 detectors:

1. Sociological argument

- Too many physicists for 1 detector

2. Moral argument

- Two detectors keep us honest

3. Risk argument

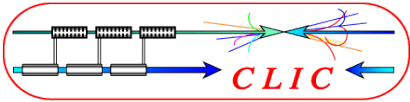
- If one breaks, we have another

4. Systematic error argument

- 2 detectors with different systematic errors
when combined give much reduced systematic error

5. Statistics argument

- low statistics regions of phase space
need 2 detectors to separate signal from noise

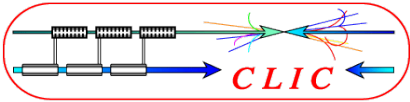


Present R&D proceeds with the following requirements :

- *Energy center of mass* $E_{CM} = 0.5 - 3 \text{ TeV}$, and beyond
- *Luminosity* $L > \text{few } 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ with acceptable background and energy spread
- Design should be compatible with a maximum *length* $\sim 50 \text{ km}$
- Total power consumption $< 500 \text{ MW}$
- Affordable (CHF, €, \$, £,.....)

Present goal:

Demonstrate all key feasibility issues and write a Conceptual Design Report (CDR) by December 2010



Some figures for LEP



LEP = Large Electron Positron collider

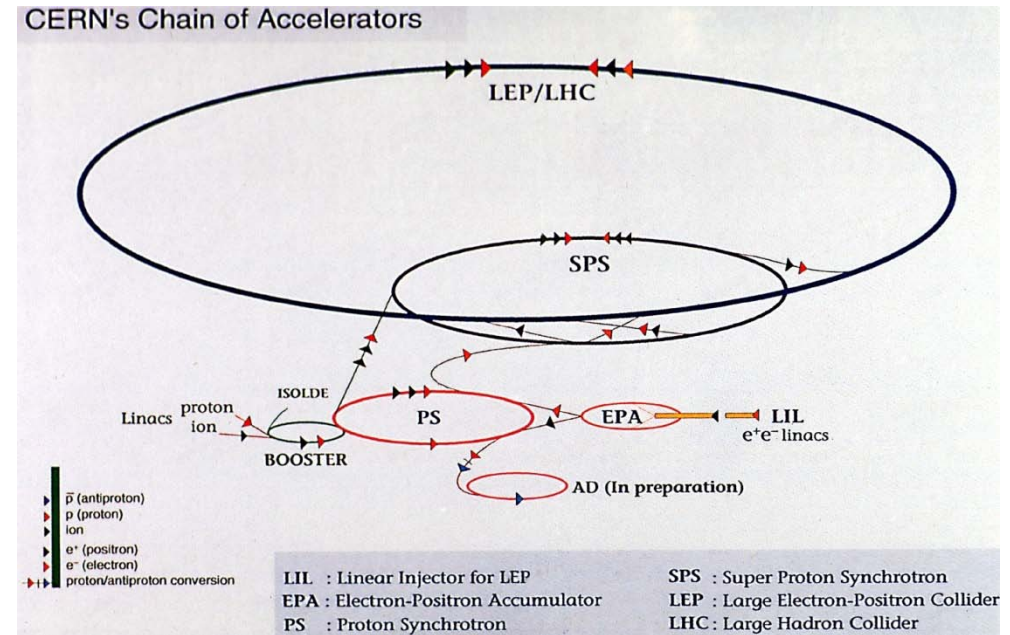
- Circumference : 27 km

- Power consumption (1998):

LPI (LIL + EPA) @ 0.5 GeV:	1 MW
PS @ 3.5 GeV:	12 MW
SPS @ 450 GEV :	52 MW
LEP @ 100 GeV :	120 MW
4 Detectors:	52 MW (Aleph, Delphi, L3, Opal)

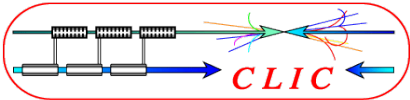
TOTAL : 237MW

- Cost: ~ 3.5 BCHF

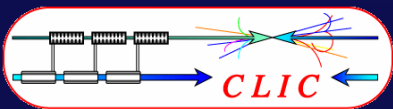




http://clic-meeting.web.cern.ch/clic-meeting/CTF3_Coordination_Mtg/Table_MoU.htm



World-wide CLIC&CTF3 Collaboration



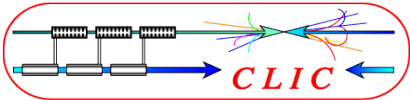
33 Institutes involving 21 funding agencies and 18 countries

Aarhus University (Denmark)
Ankara University (Turkey)
Argonne National Laboratory (USA)
Athens University (Greece)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
Gazi Universities (Turkey)

Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
INFN / LNF (Italy)
Instituto de Fisica Corpuscular (Spain)
IRFU / Saclay (France)
Jefferson Lab (USA)
John Adams Institute (UK)

JINR (Russia)
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Oslo University (Norway)

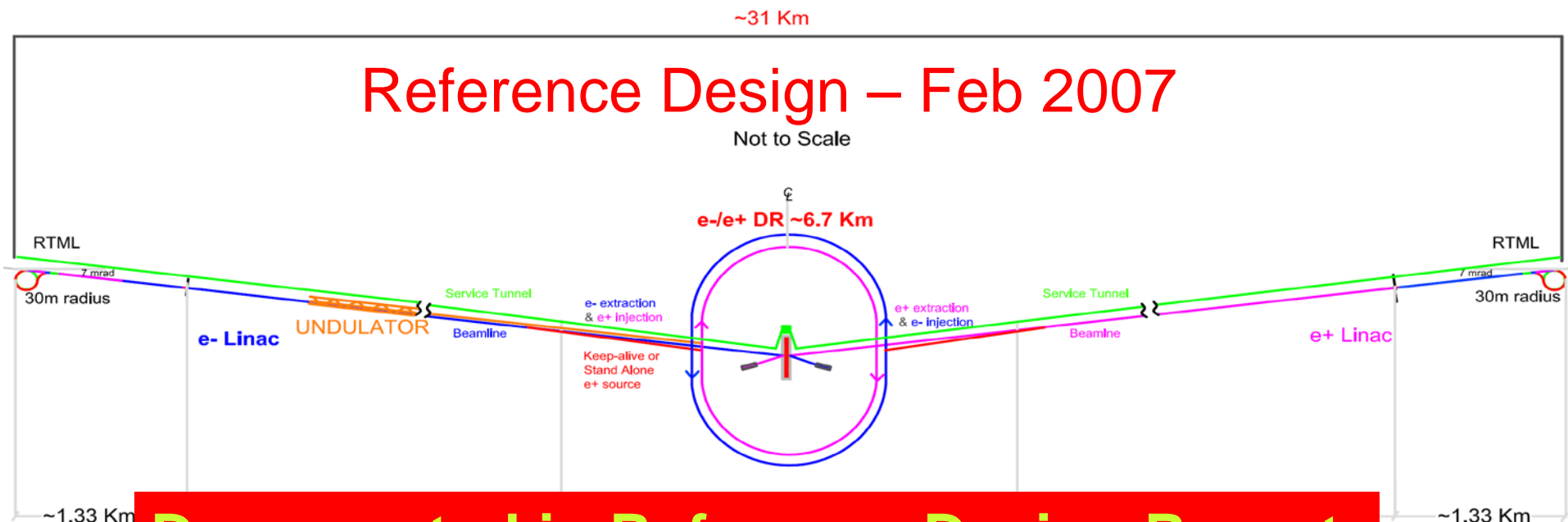
Patras University (Greece)
Polytech. University of Catalonia (Spain)
PSI (Switzerland)
RAL (UK)
RRCAT / Indore (India)
SLAC (USA)
Thrace University (Greece)
Uppsala University (Sweden)



International Linear Collider (ILC)

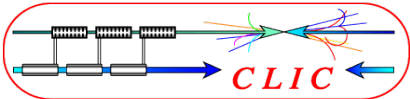


- 11km SC linacs operating at 31.5 MV/m for 500 GeV
- Centralized injector
 - Circular damping rings for electrons and positrons
 - Undulator-based positron source
- Single IR with 14 mrad crossing angle
- Dual tunnel configuration for safety and availability



Documented in Reference Design Report

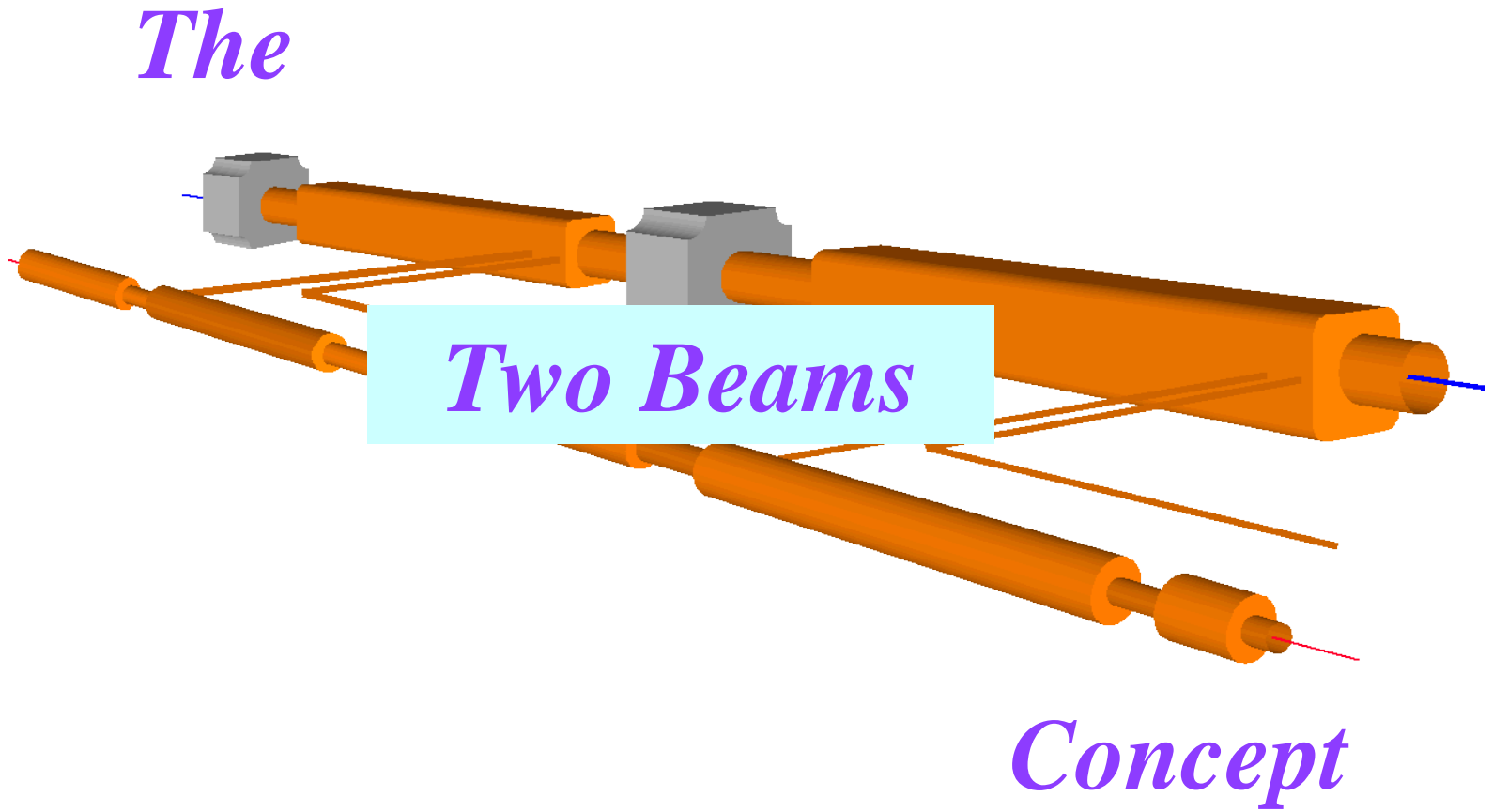
Schematic Layout of the 500 GeV Machine

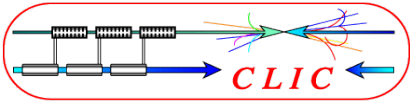


	CLIC	ILC
Physics & Detectors	L.Linssen, D.Schlatter	F.Richard, S.Yamada
Beam Delivery System (BDS) & Machine Detector Interface (MDI)	L.Gatignon D.Schulte, R.Tomas Garcia	B.Parker, A.Seriy
Civil Engineering & Conventional Facilities	C.Hauviller, J.Osborne.	J.Osborne, V.Kuchler
Positron Generation	L.Rinolfi	J.Clarke
Damping Rings	Y.Papaphilipou	M.Palmer
Beam Dynamics	D.Schulte	A.Latina, K.Kubo, N.Walker
Cost & Schedule	P.Lebrun, K.Foraz, G.Riddone	J.Carwardine, P.Garbincius, T.Shidara

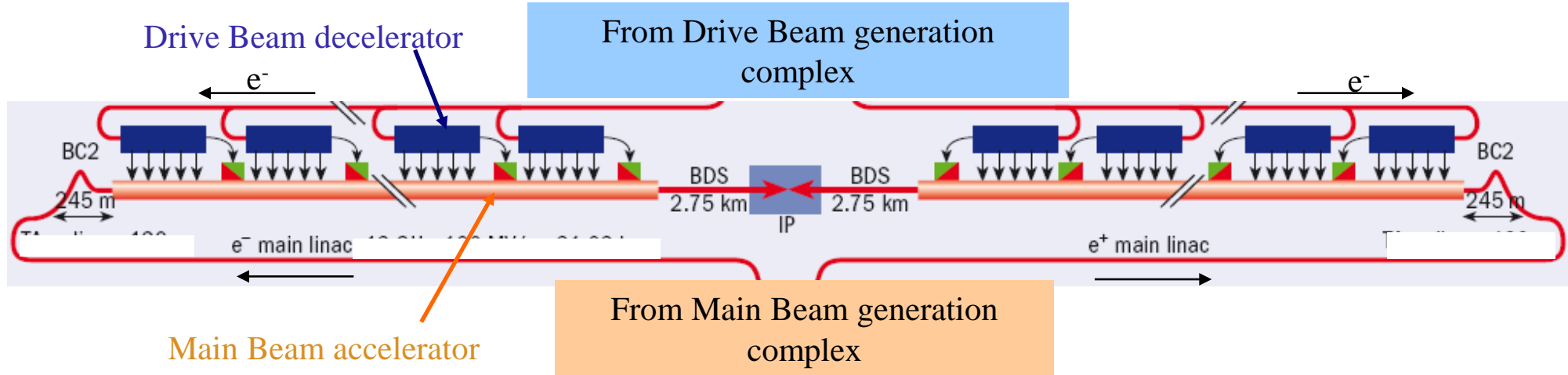
B. Barish
12-Oct-09
CLIC Workshop

Global Design Effort



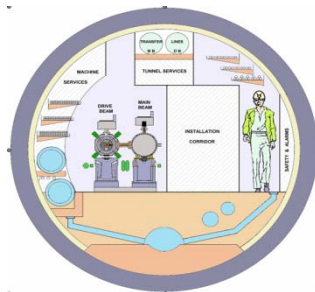


The basic layout for a Two-Beam scheme



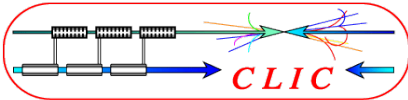
➤ High acceleration gradient and high frequency

- “Compact” collider
- Normal conducting accelerating structures

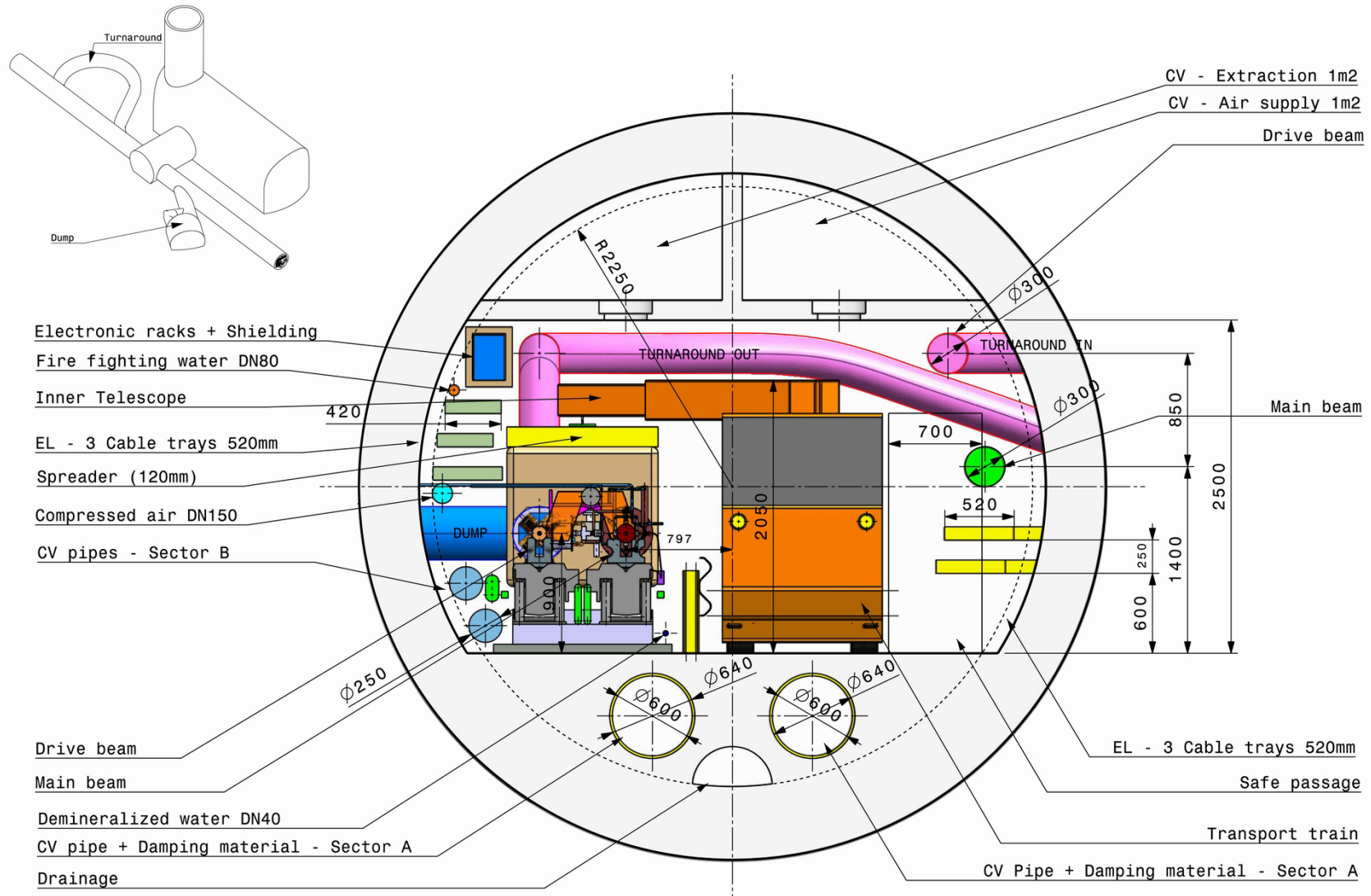


➤ Two-Beam Acceleration Scheme

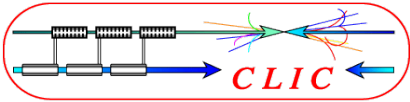
- Simple tunnel, no active elements
- Modular, easy energy upgrade in stages



The CLIC tunnel in October 2009



CLIC - Typical Cross Section - Diameter 4500mm - Junction with Turnaround - 1:25
Draft - J.Osborne / A.Kosmicki -October 12th 2009



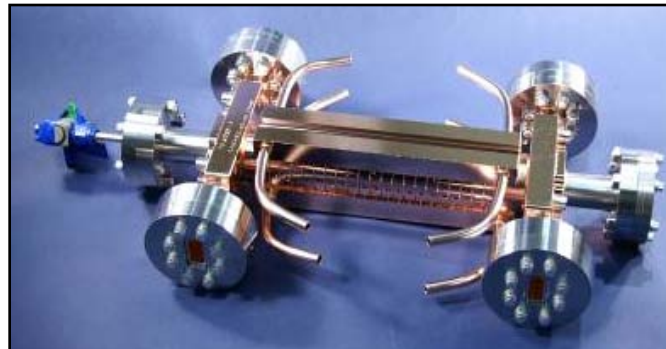
Why CLIC parameters changed in 2007 ?



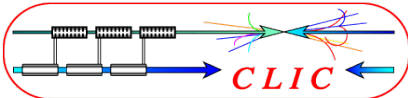
- Close to maximum Performance and minimum Cost
- Very close to the NLC and JLC frequency: 11.4 GHz
Use the wide expertise at SLAC and KEK
- Stand alone power sources available
- Easier fabrication (tolerances, vacuum)
- Nominal accelerating gradient already demonstrated at low breakdown rate

Structure T18_vg4.2

- designed by CERN
- built at KEK,
- assembled and bonded in SLAC
- tested at SLAC (NLCTA).



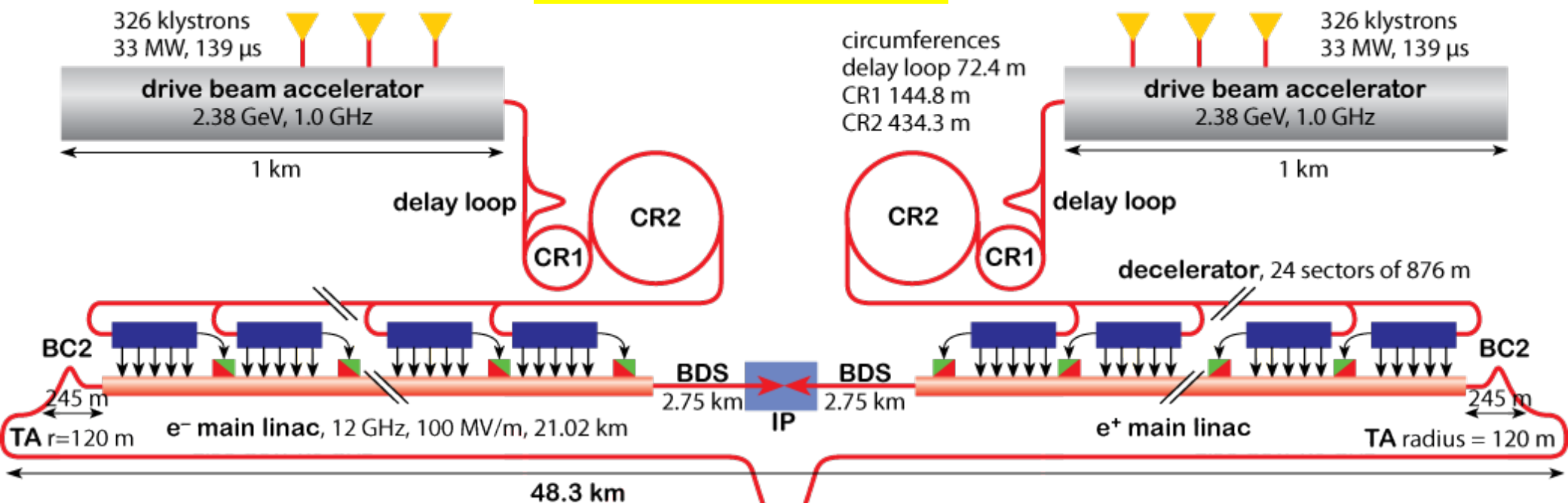
100 MV/m, 240 ns,
 10^{-7} m^{-1} brkdwn rate



General CLIC layout for 3 TeV



Drive Beam Generation



CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump

booster linac, 6.14 GeV

e⁻ injector,
2.86 GeV

e⁻
PDR
398 m

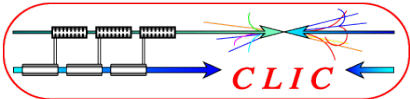
e⁻
DR
493 m

e⁺
DR
493 m

e⁺
PDR
398 m

e⁺ injector,
2.86 GeV

Main Beam Generation

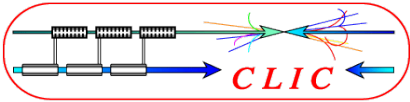


CLIC nominal parameters at I.P.

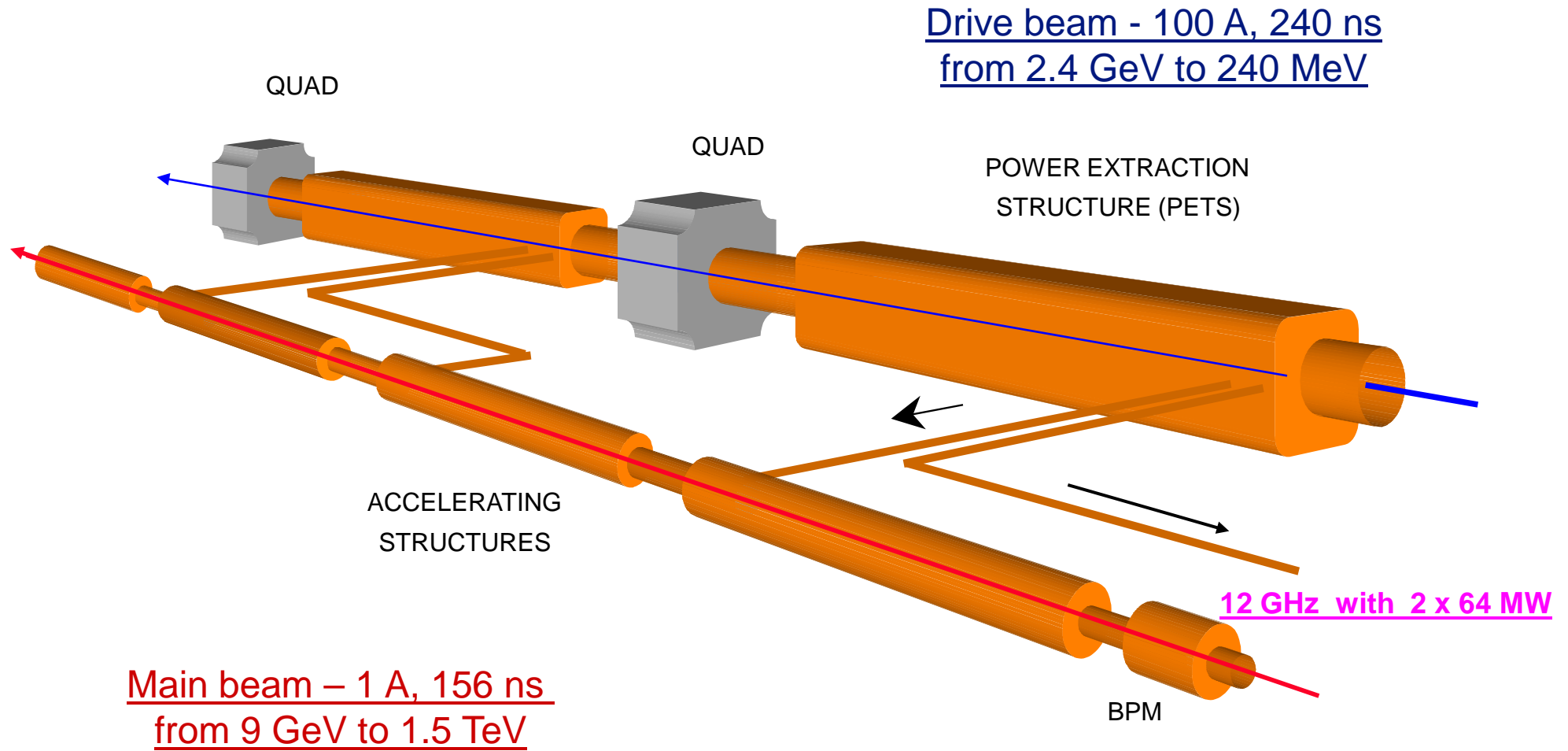


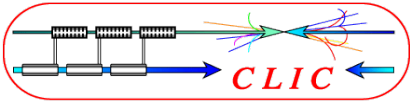
October 2009

Center-of-mass energy	3 TeV
Peak Luminosity	$5.9 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
Peak luminosity (in 1% of energy)	$2 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
Repetition rate	50 Hz
Loaded accelerating gradient	100 MV/m
Main linac RF frequency	12 GHz
Overall two-linac length	42 km
Bunch charge	$3.72 \cdot 10^9$
Bunch separation	0.5 ns
Beam pulse duration	156 ns
Beam power/beam	14 MW
Horizontal / vertical normalized emittance	660 / 20 nm rad
Horizontal / vertical beam size before pinch	40 / 1 nm
Total site length	48 km
Wall plug to beam transfer efficiency	6.8 %
Total power consumption	415 MW

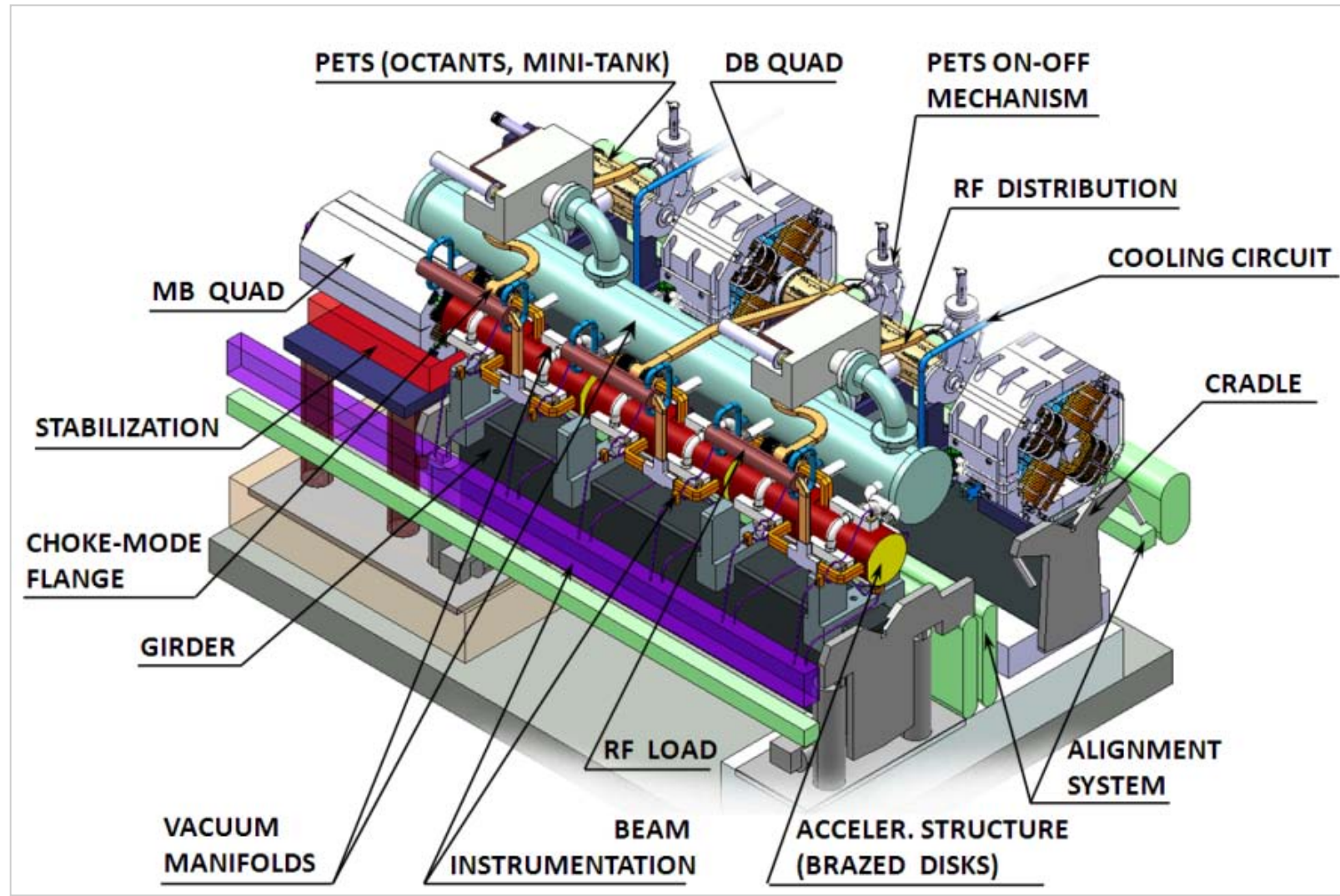


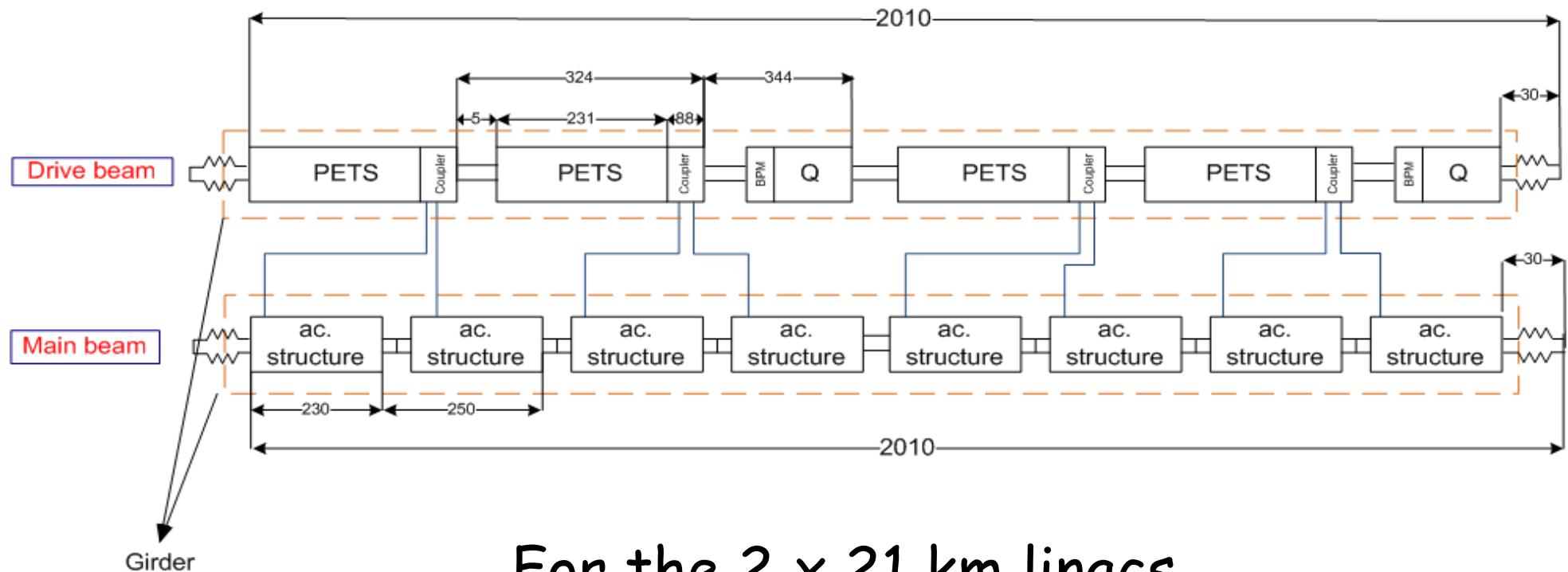
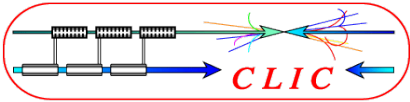
CLIC Two-Beam module





CLIC Two-Beam Module



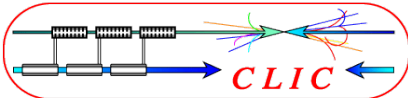


For the 2 x 21 km linacs

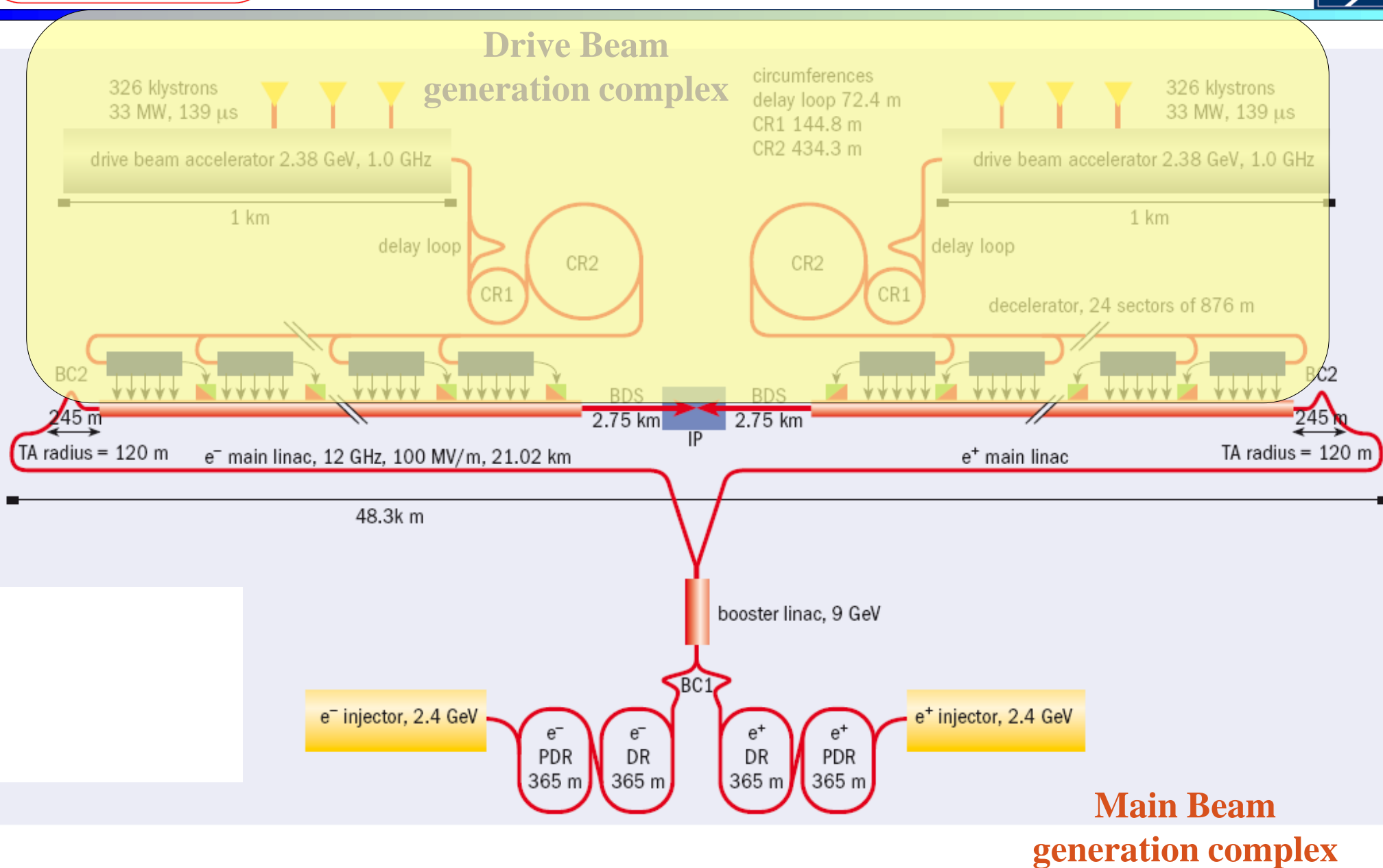
20760 CLIC modules of 2.010 m each

71460 Power Extraction and Transfer Structures (PETS) for the Drive Beams

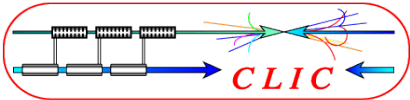
143010 CLIC Accelerating Structures (CAS) for the Main Beams



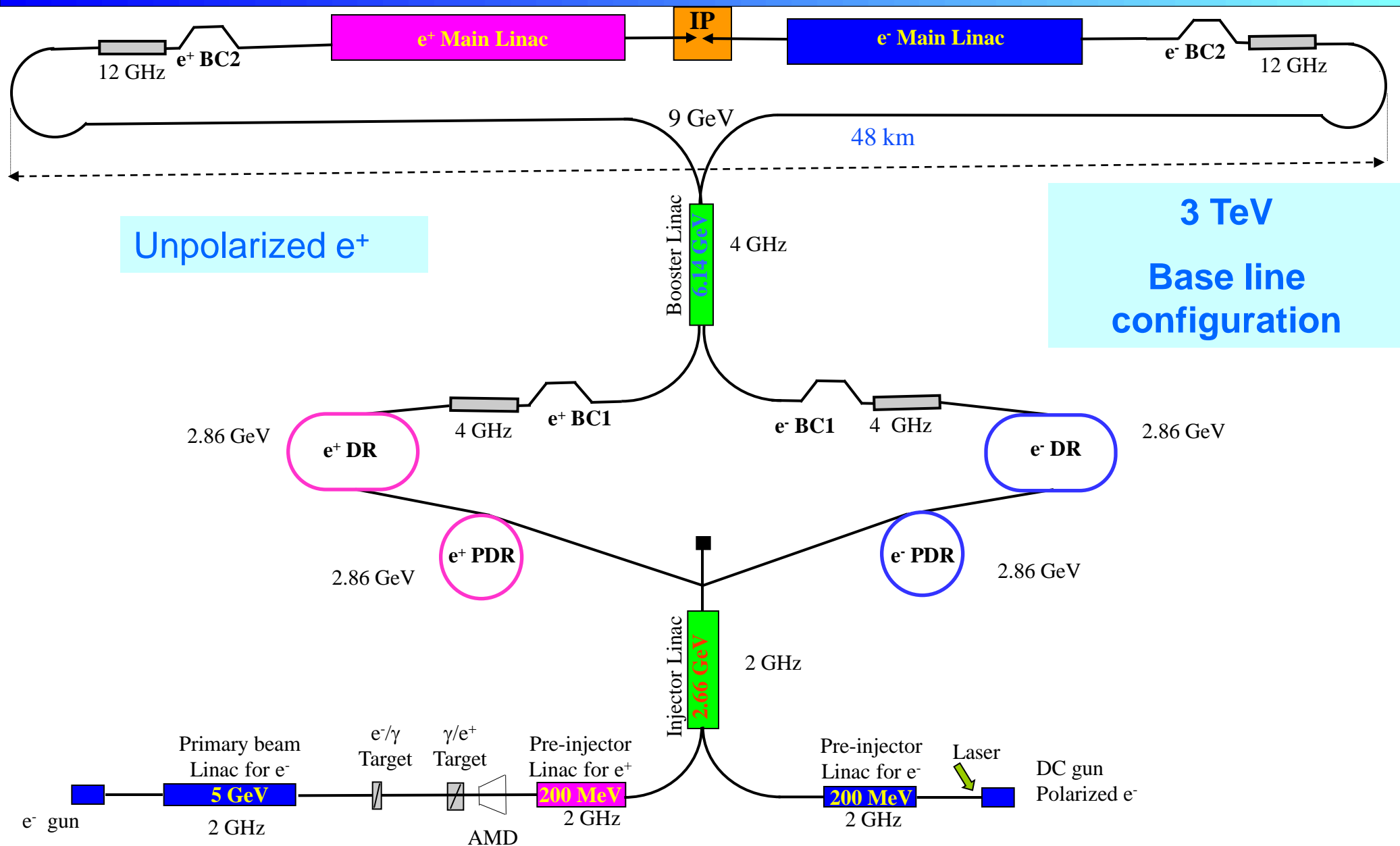
CLIC Main Beam Injector complex

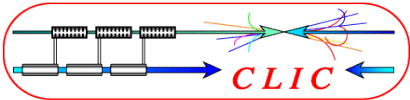


**Main Beam
generation complex**



CLIC Main Beam Injector Complex

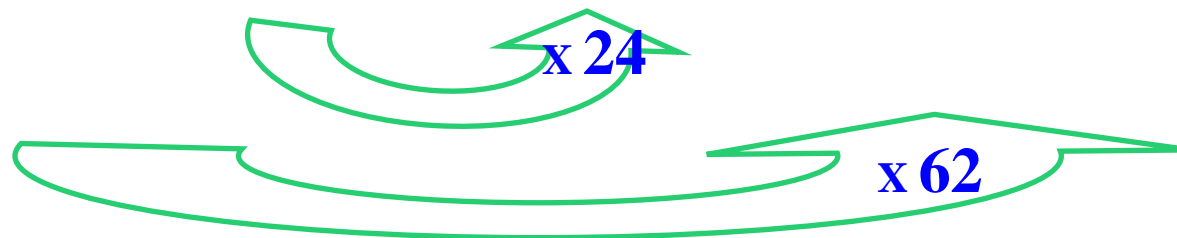


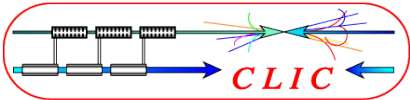


Flux of e^+



	SLC	CLIC	ILC	LHeC
e^+ / bunch	3.5×10^{10}	0.67×10^{10}	2×10^{10}	1.5×10^{10}
Bunches / macropulse	1	312	2625	20833
Macropulse Rep. Rate.	120	50	5	10
e^+ / second	0.042×10^{14}	1×10^{14}	2.6×10^{14}	31×10^{14}

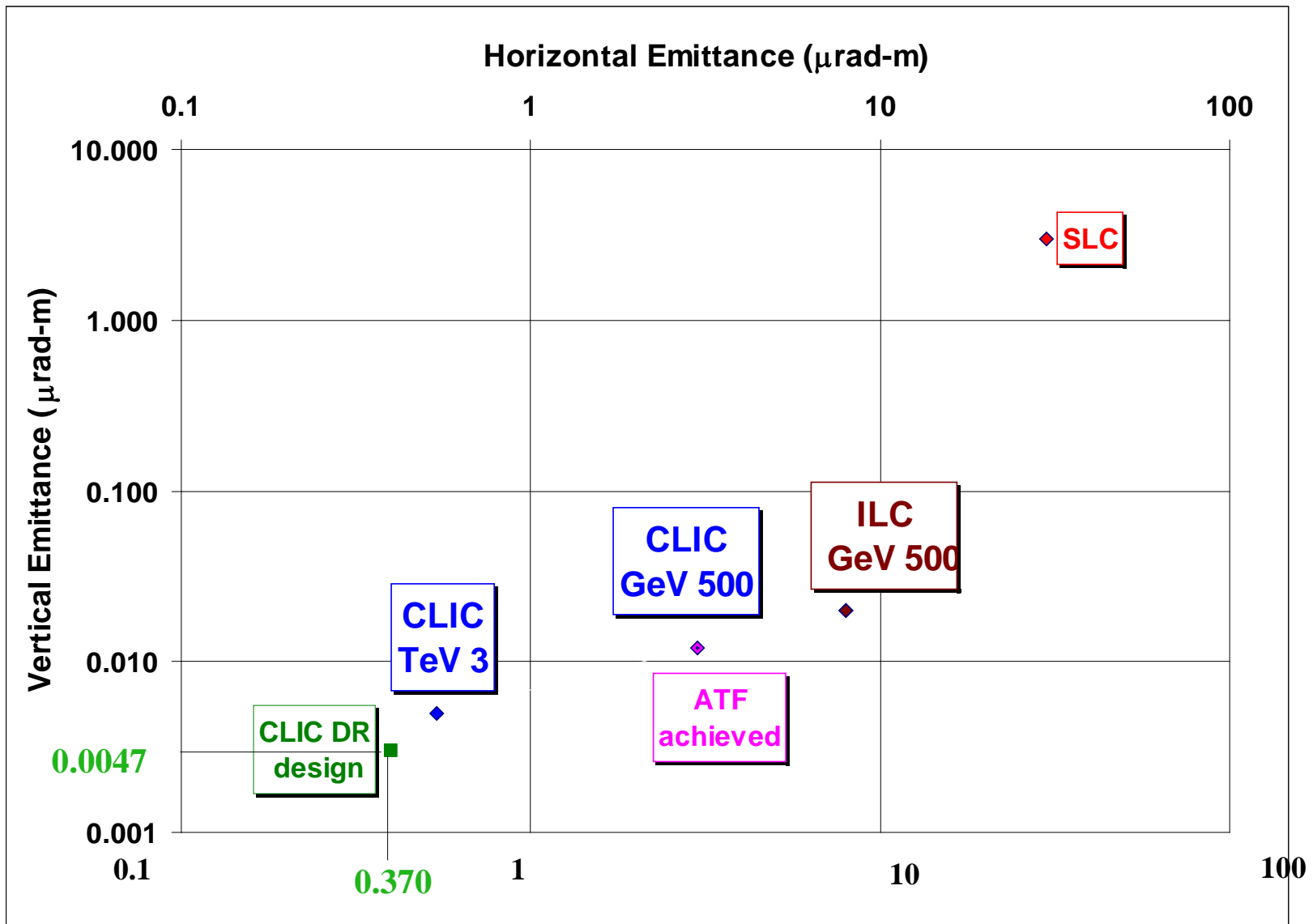




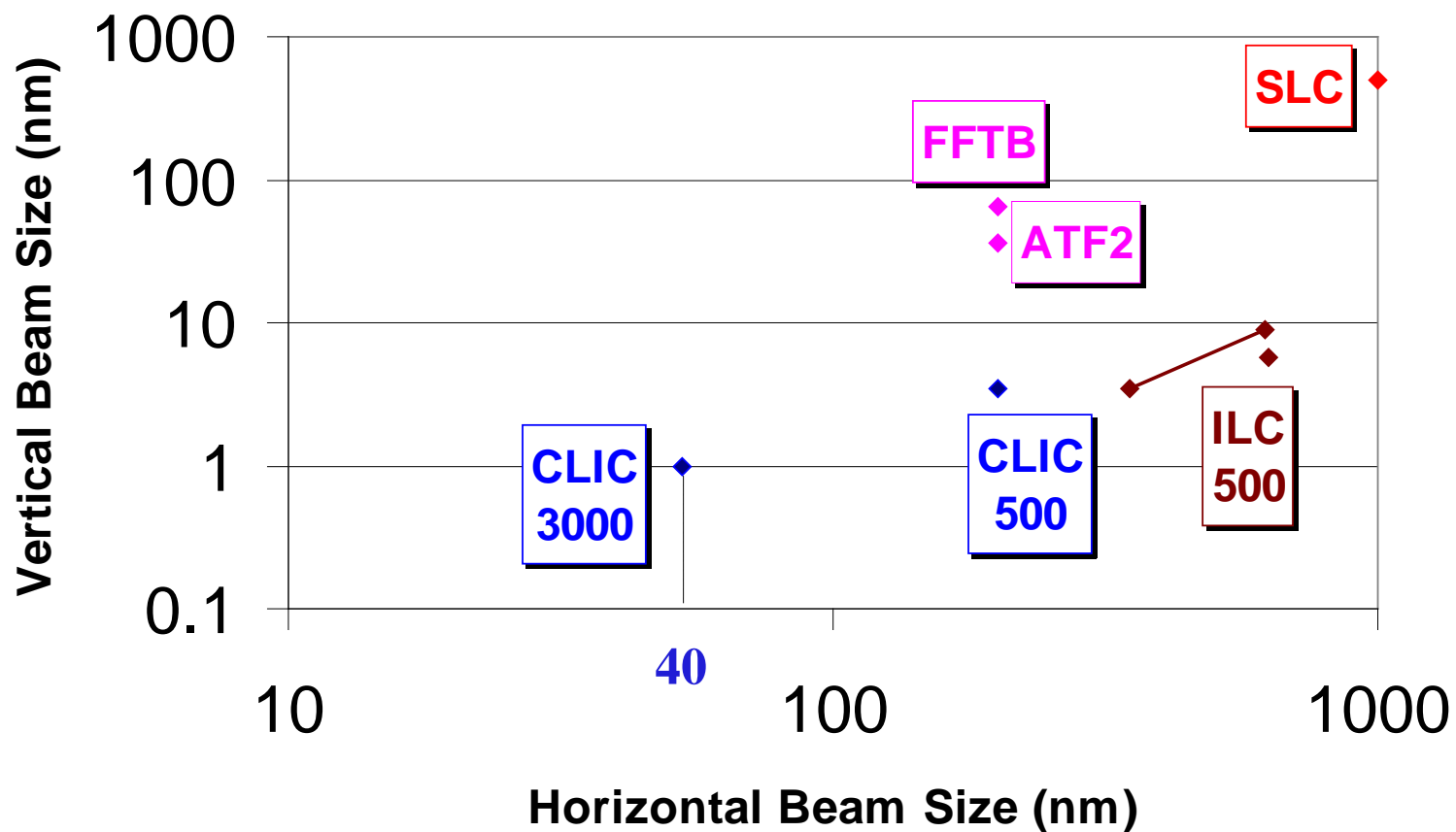
The challenge of the small beam emittances

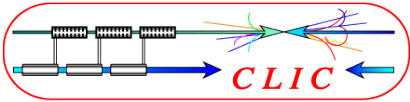


Normalized rms emittances at the Damping Ring extraction



R.M.S. Beam Sizes at Collision in Linear Colliders

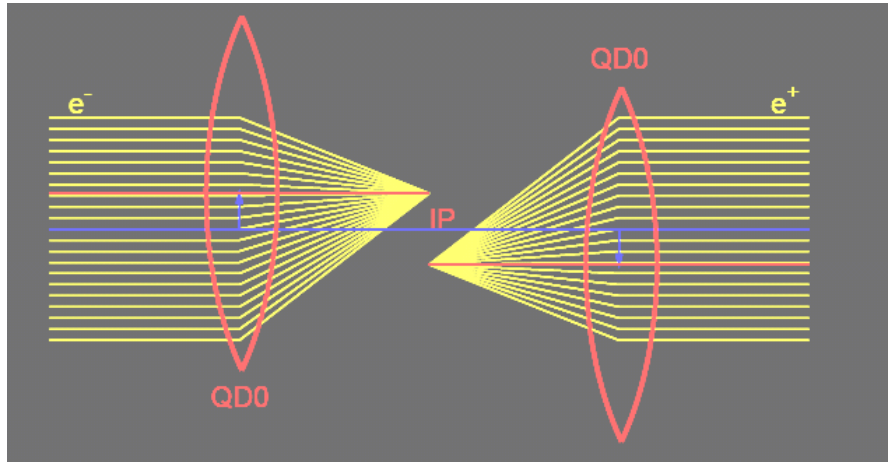




The challenge of stability

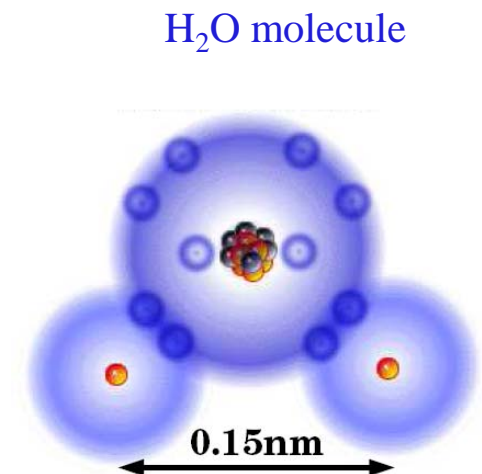


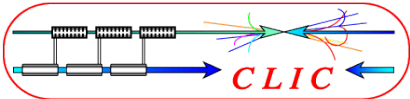
Vertical spot size at IP is **1 nm**



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

Magnet	Horizontal jitter	Vertical jitter
Linac (2600 quads)	14 nm	1.3 nm
Final Focus (2 quads) QD0	4 nm	0.15 nm

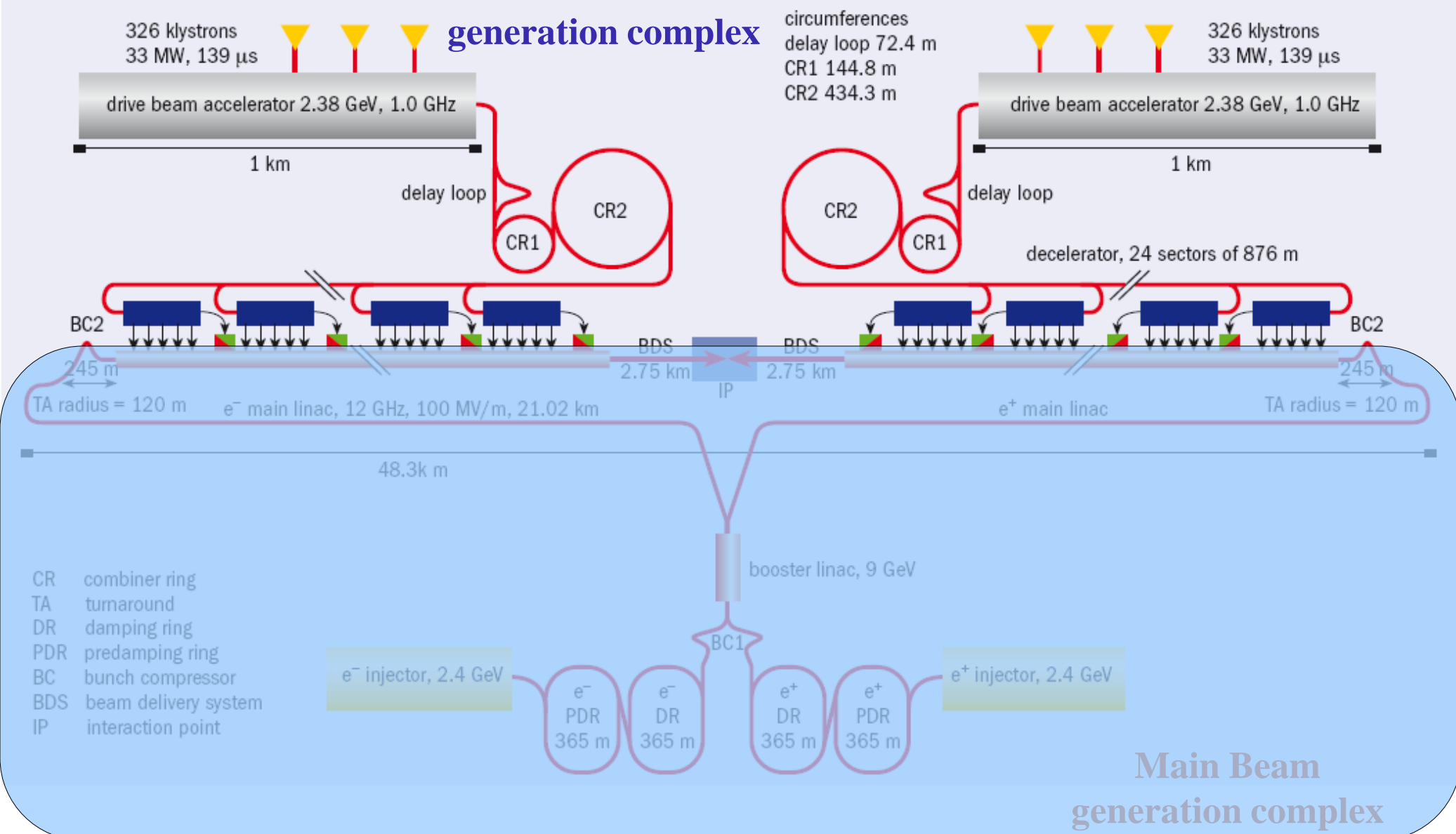




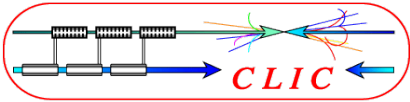
CLIC Drive Beam complex



Drive Beam generation complex



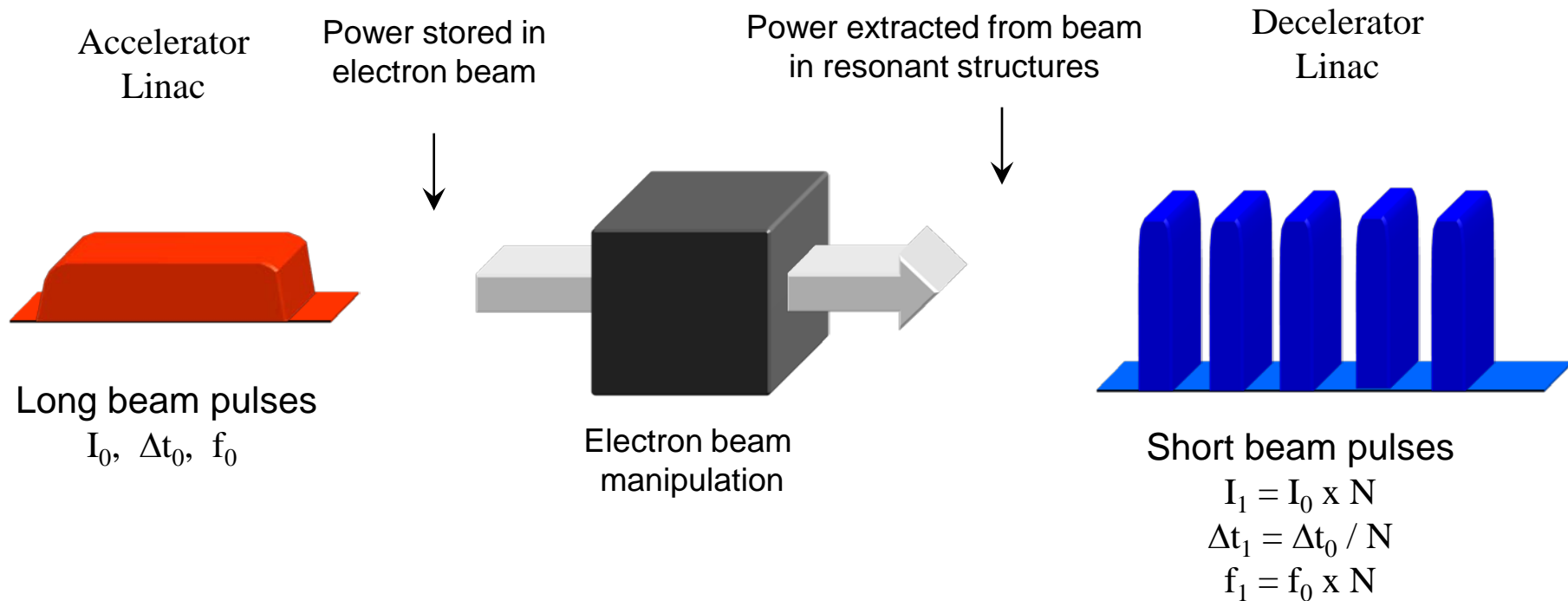
Main Beam generation complex

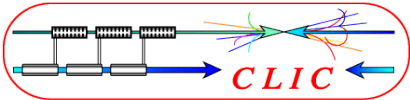


What does the RF power source do ?

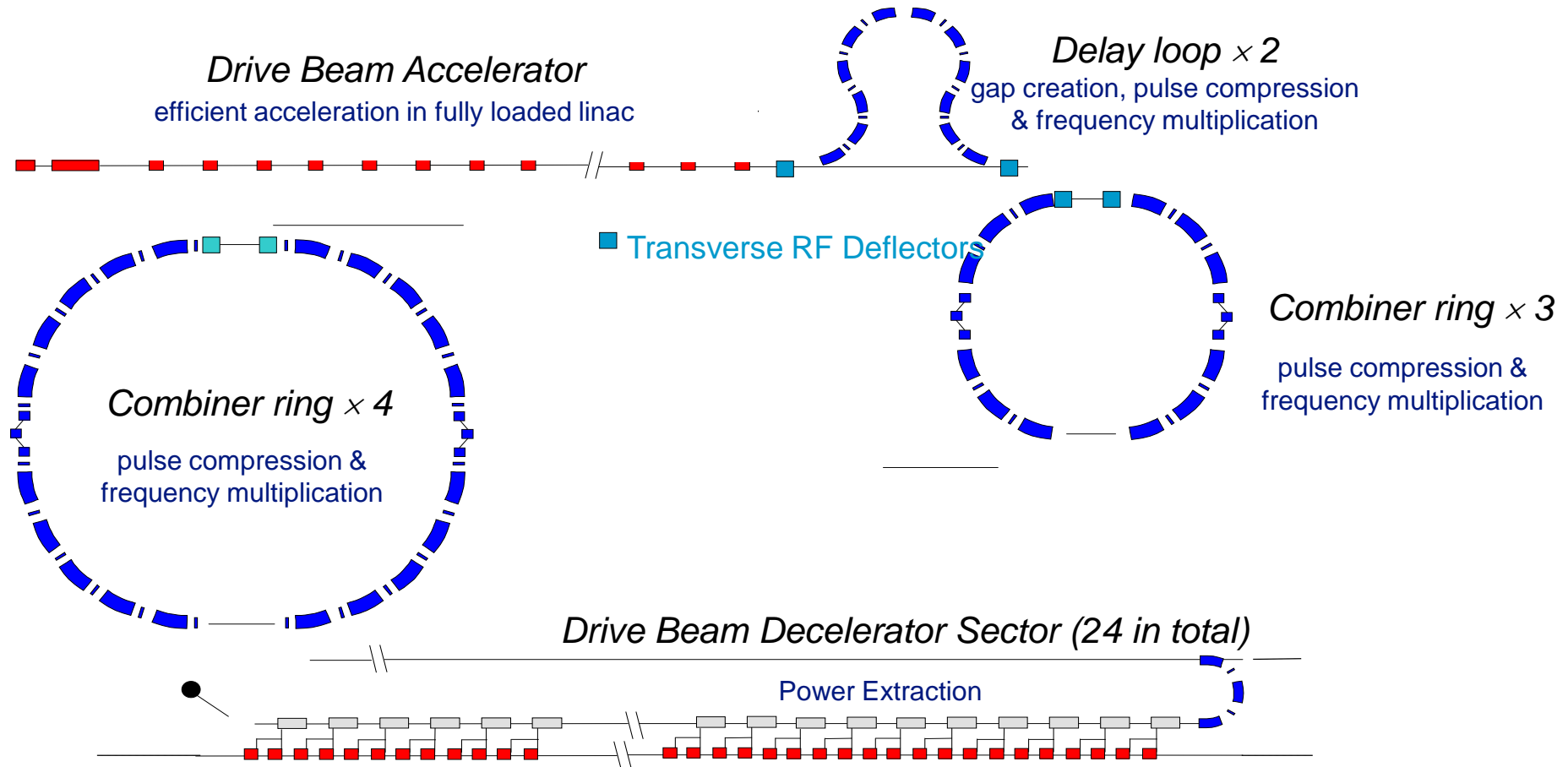


The CLIC RF power source can be described as a “black box”, combining *very long beam pulses*, and transforming them in *many short pulses*, with *higher intensity* and with *higher frequency*



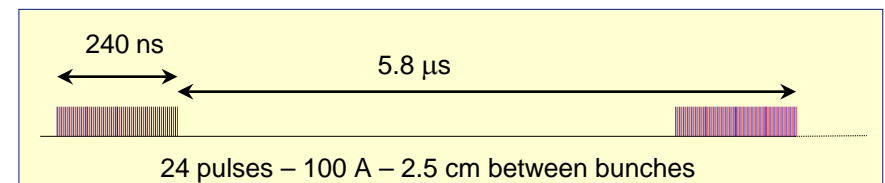
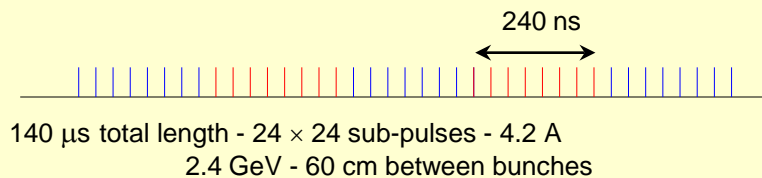


The Drive Beam generation

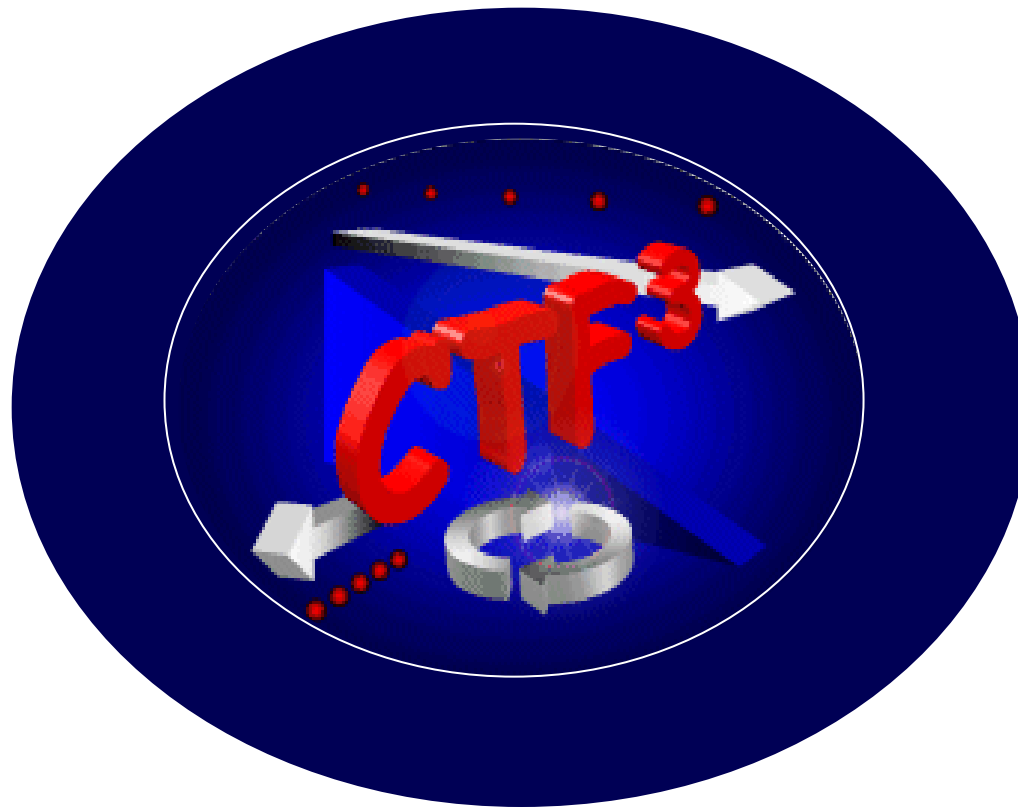


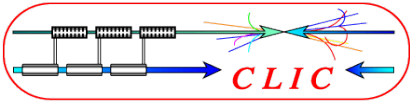
Drive beam time structure - initial

Drive beam time structure - final



The CLIC Test Facilities





1988-1995: CTF = CLIC Test Facility 1

First Test Facility with a single beam making demonstration of acceleration with high gradient based on 30 GHz RF power

1995-2002: CTF 2 = CLIC Test Facility 2

Second Test Facility for demonstration of the two beams acceleration concept

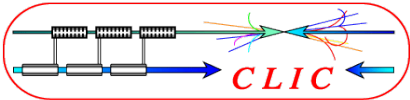
High gradient tests in single cells 30 GHz cavities

2001-2003: CTF 3 = CLIC Test Facility 3 (Preliminary phase)

Third Test Facility for demonstration of the RF frequency multiplication by a factor 4

2003-2010: CTF 3 = CLIC Test Facility 3

Demonstration of the fully loaded linac and all CLIC technology-related key issues initially listed in the ILC-TRC 2003 report and reviewed by the CLIC Advisory Committee in May 2009

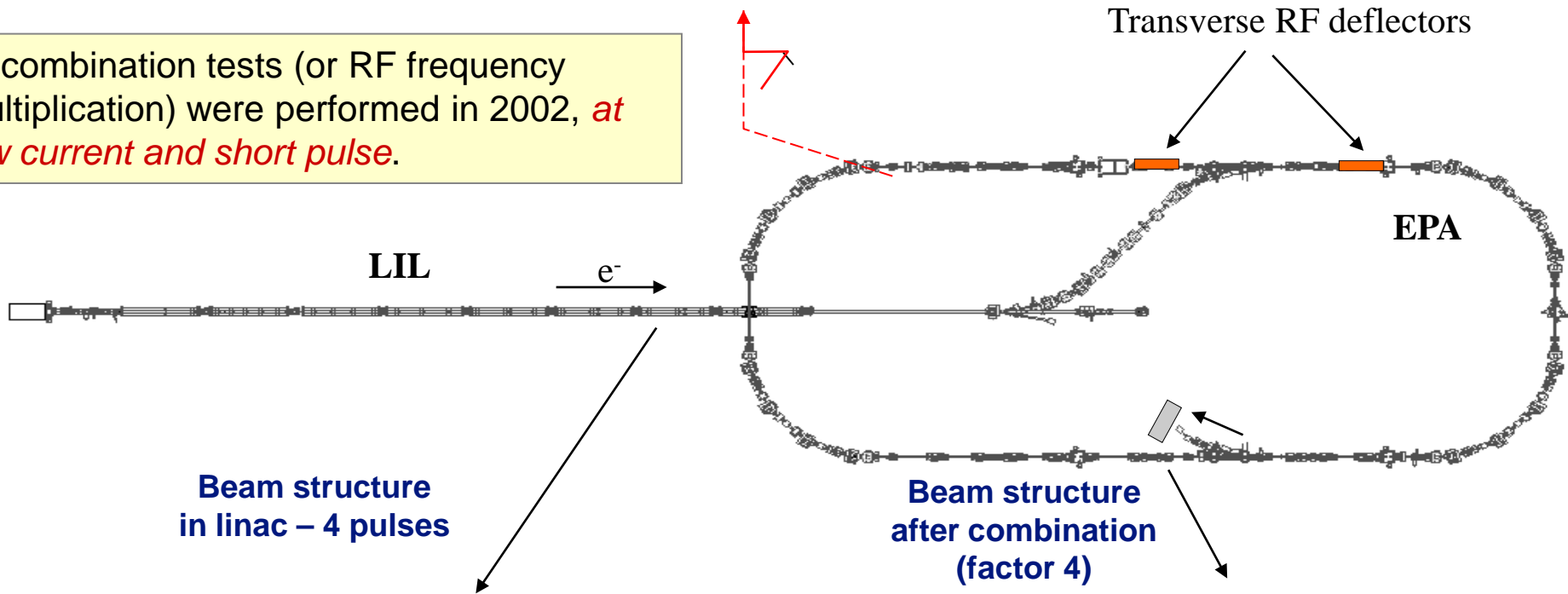


Recombination of electron beam pulses



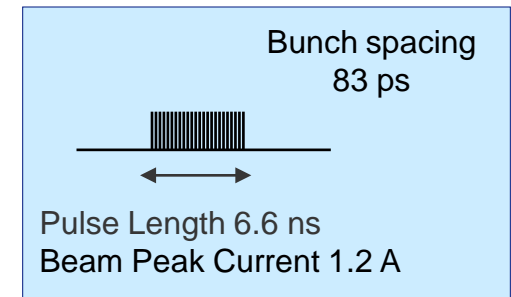
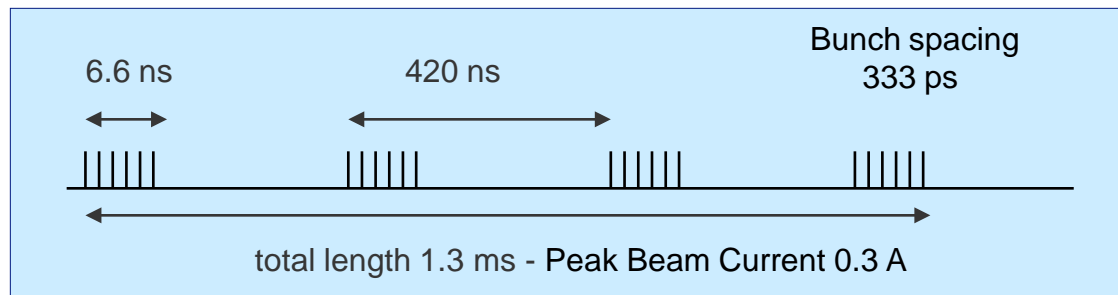
Recombination tests (or RF frequency multiplication) were performed in 2002, *at low current and short pulse.*

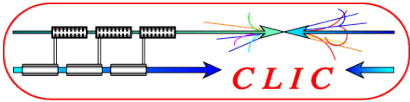
streak camera measurement



Beam structure in linac - 4 pulses

Beam structure after combination (factor 4)

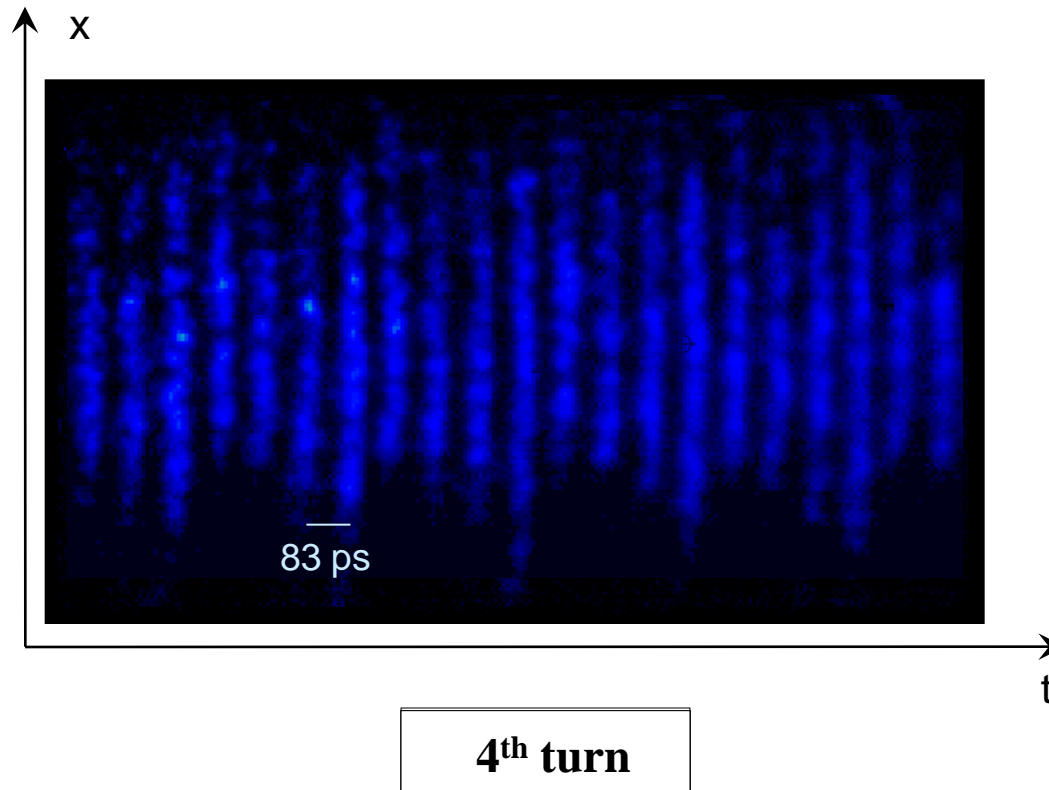




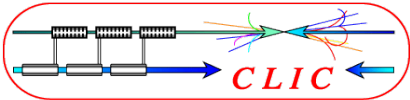
Streak camera images



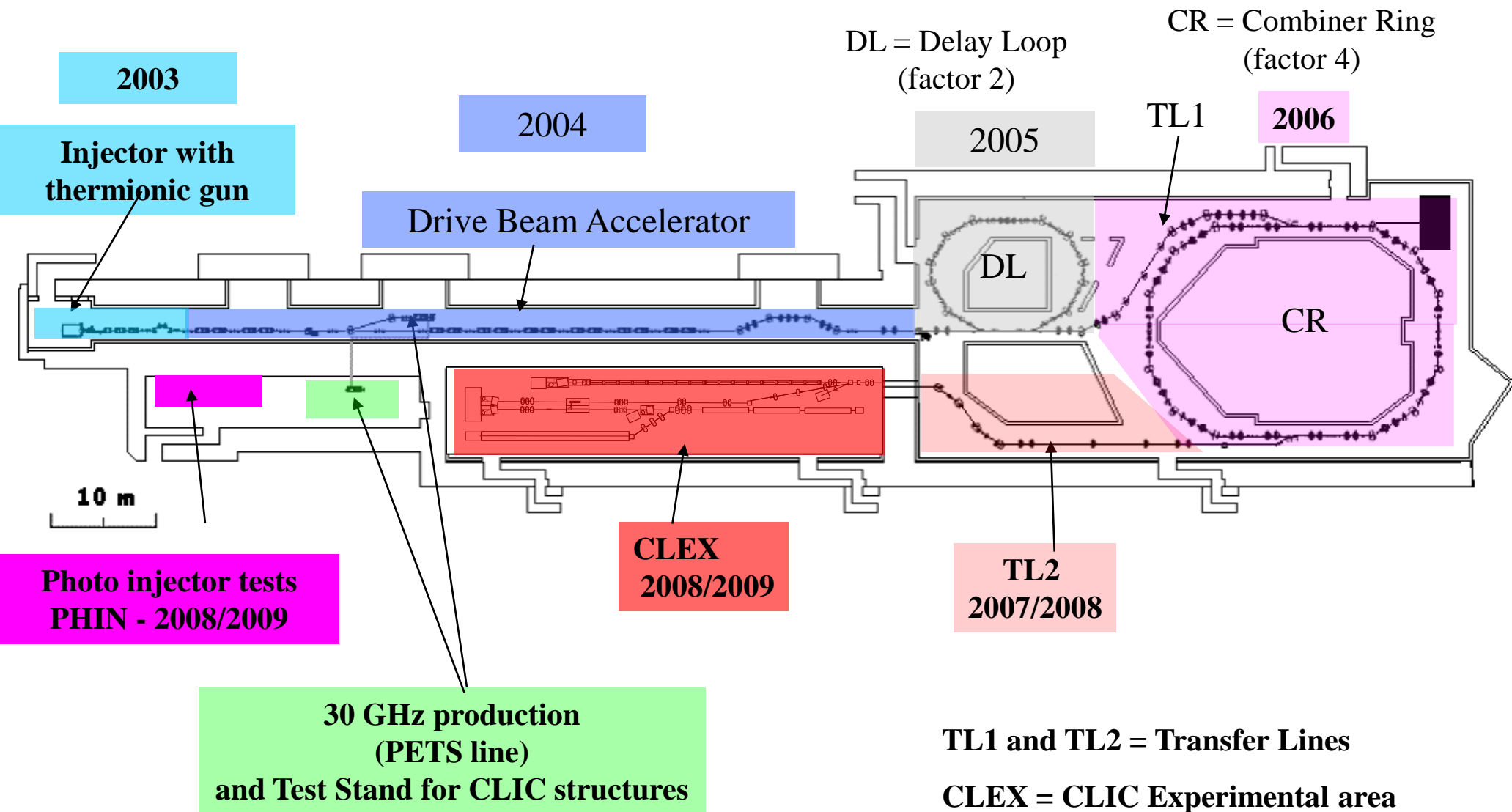
Recorded during the CTF 3 Preliminary phase

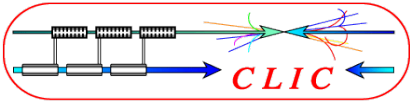


Showing the bunch combination process or RF
frequency multiplication by a factor 4

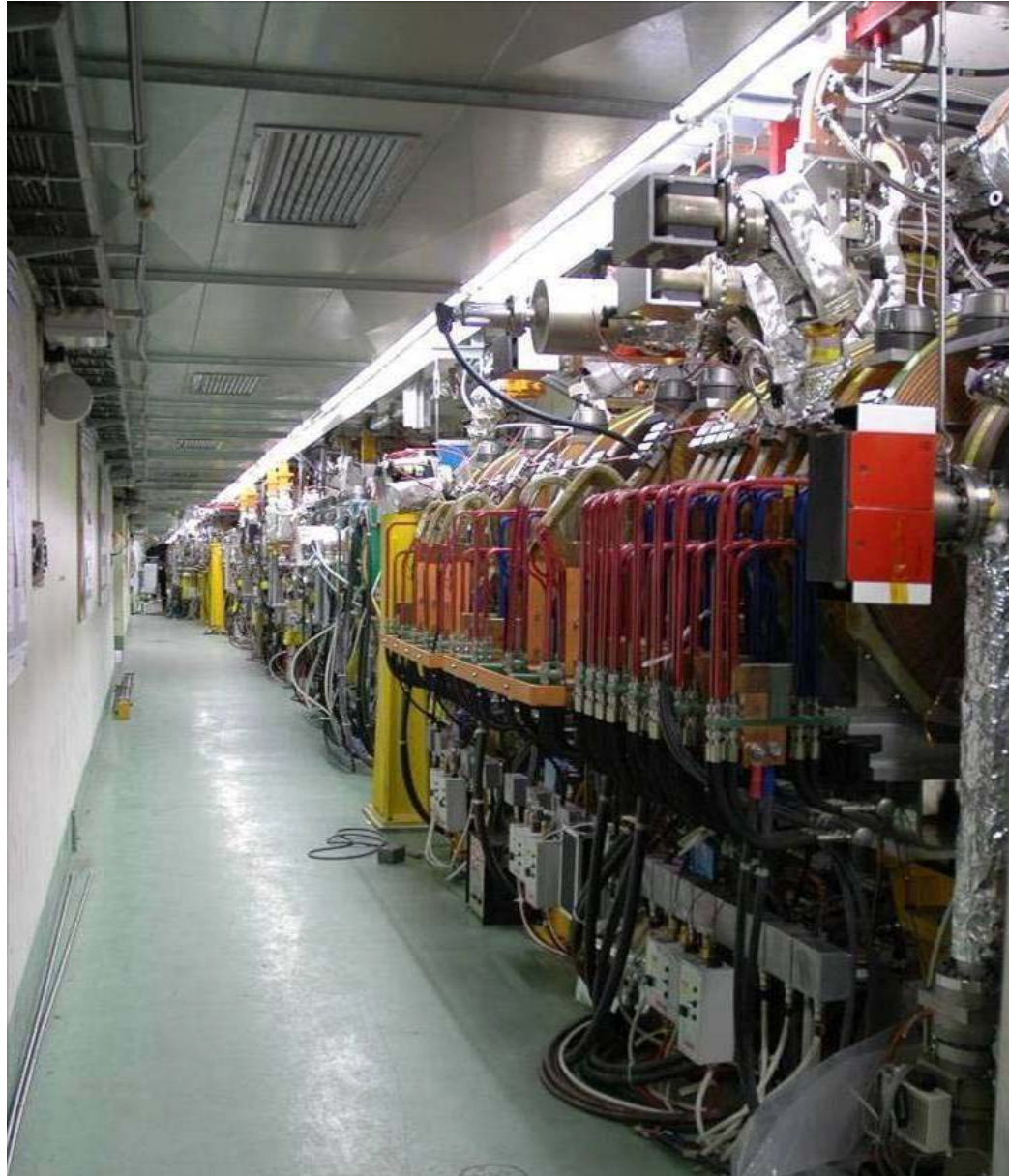


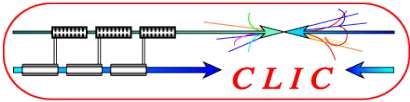
CTF3 evolution



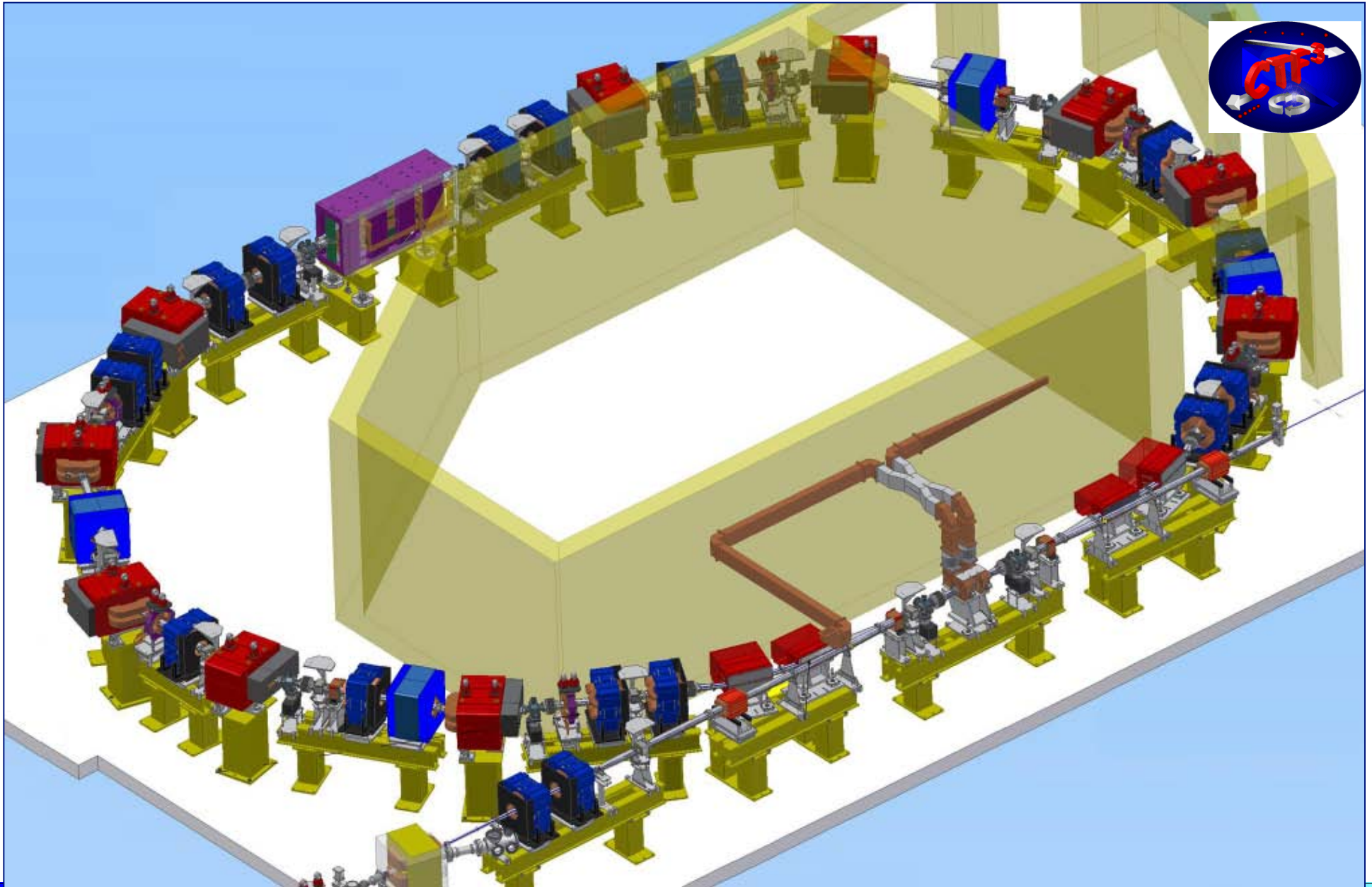


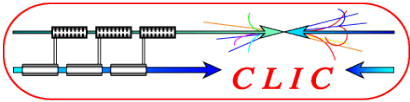
CTF3 Injector Linac



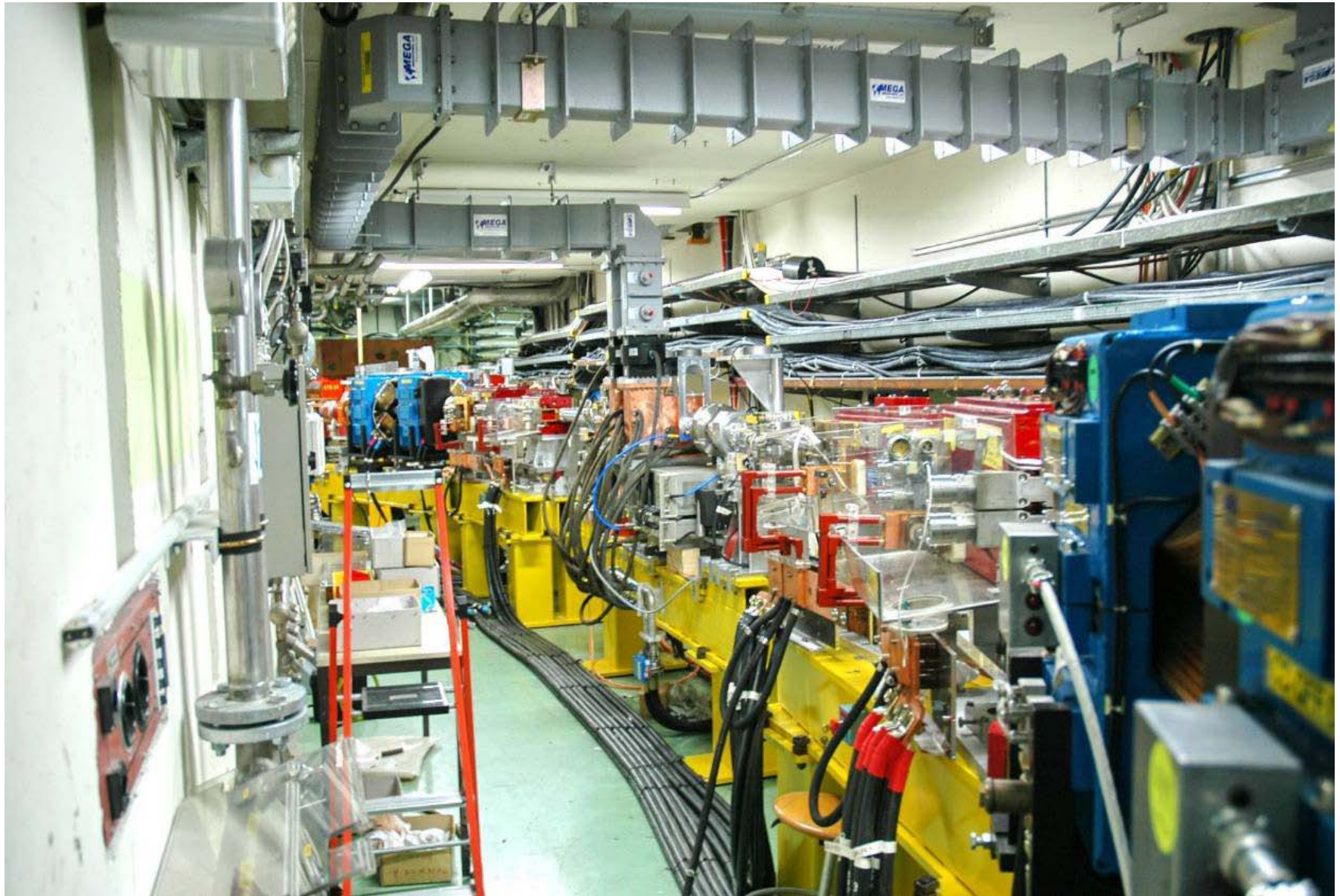


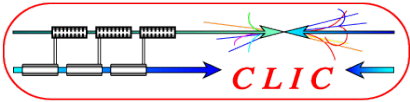
Delay Loop





Delay Loop Injection area

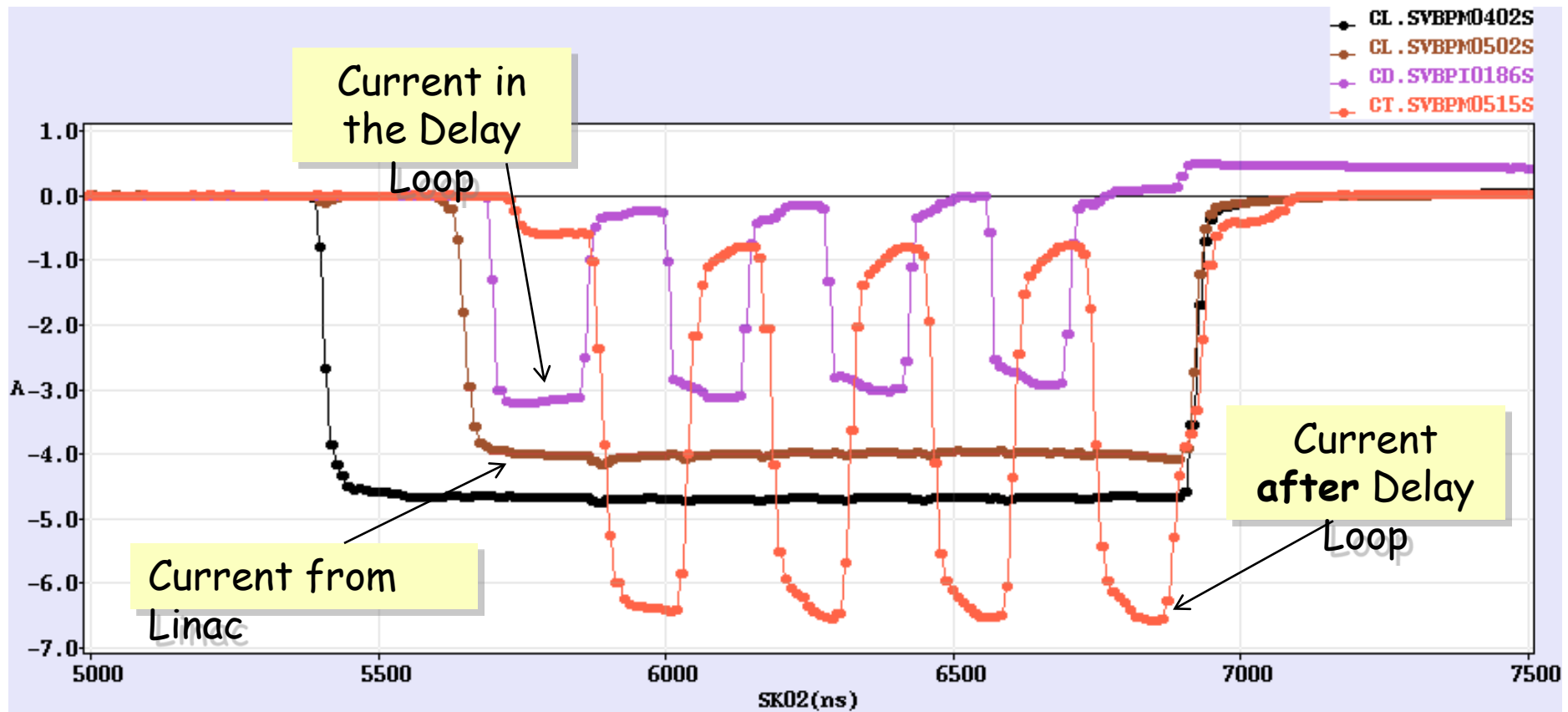
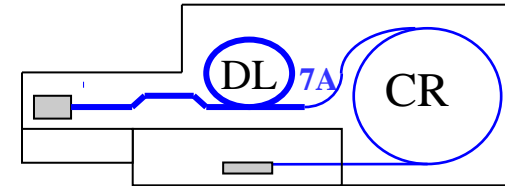


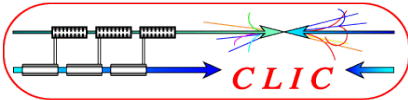


Beam recombination in the Delay Loop

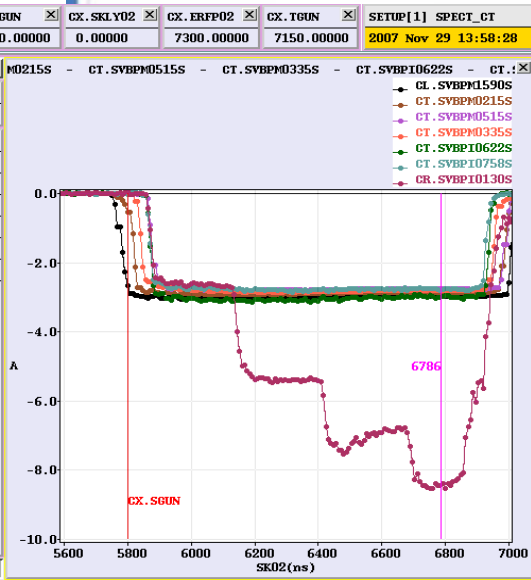
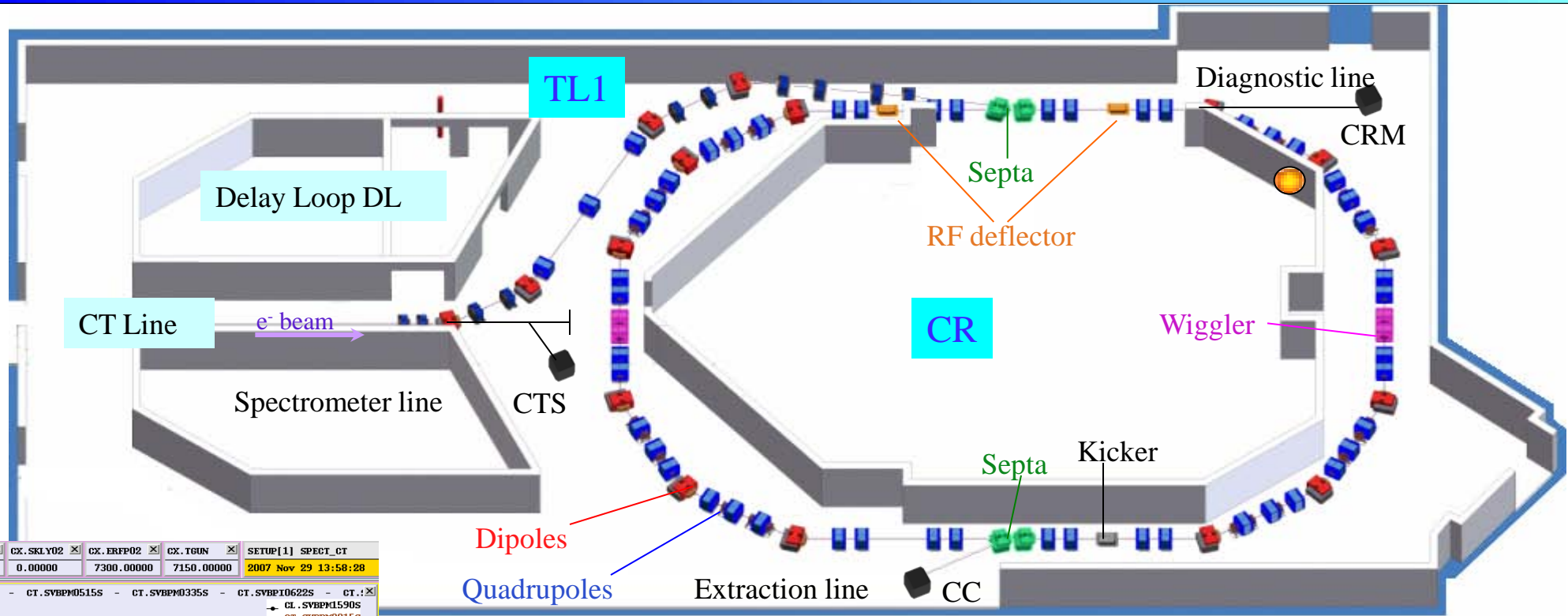


- factor 2 combination
- current about doubled, from ~ 3.5 A to ~ 6.5 A (0.5 A in satellites)

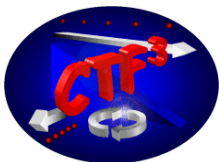


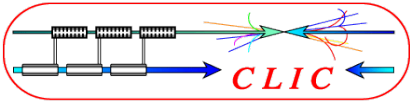


Combiner Ring



First combination with a factor 4
(November `07)

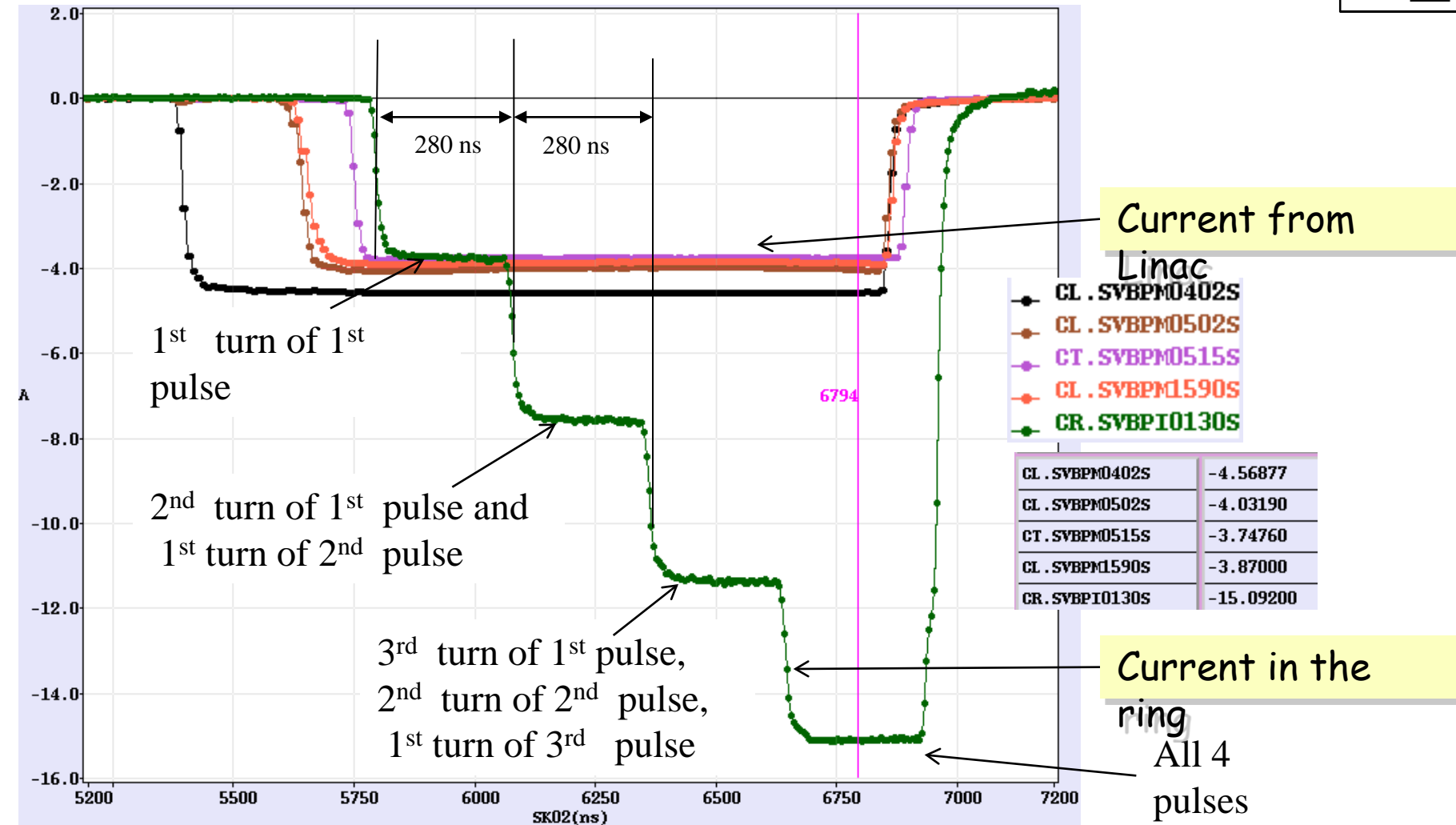
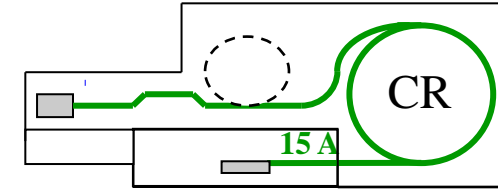


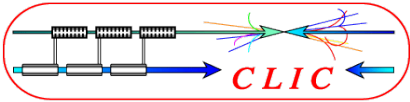


Beam recombination in the Combiner Ring



- factor 4 combination achieved with 15 A, 280 ns (without Delay Loop)

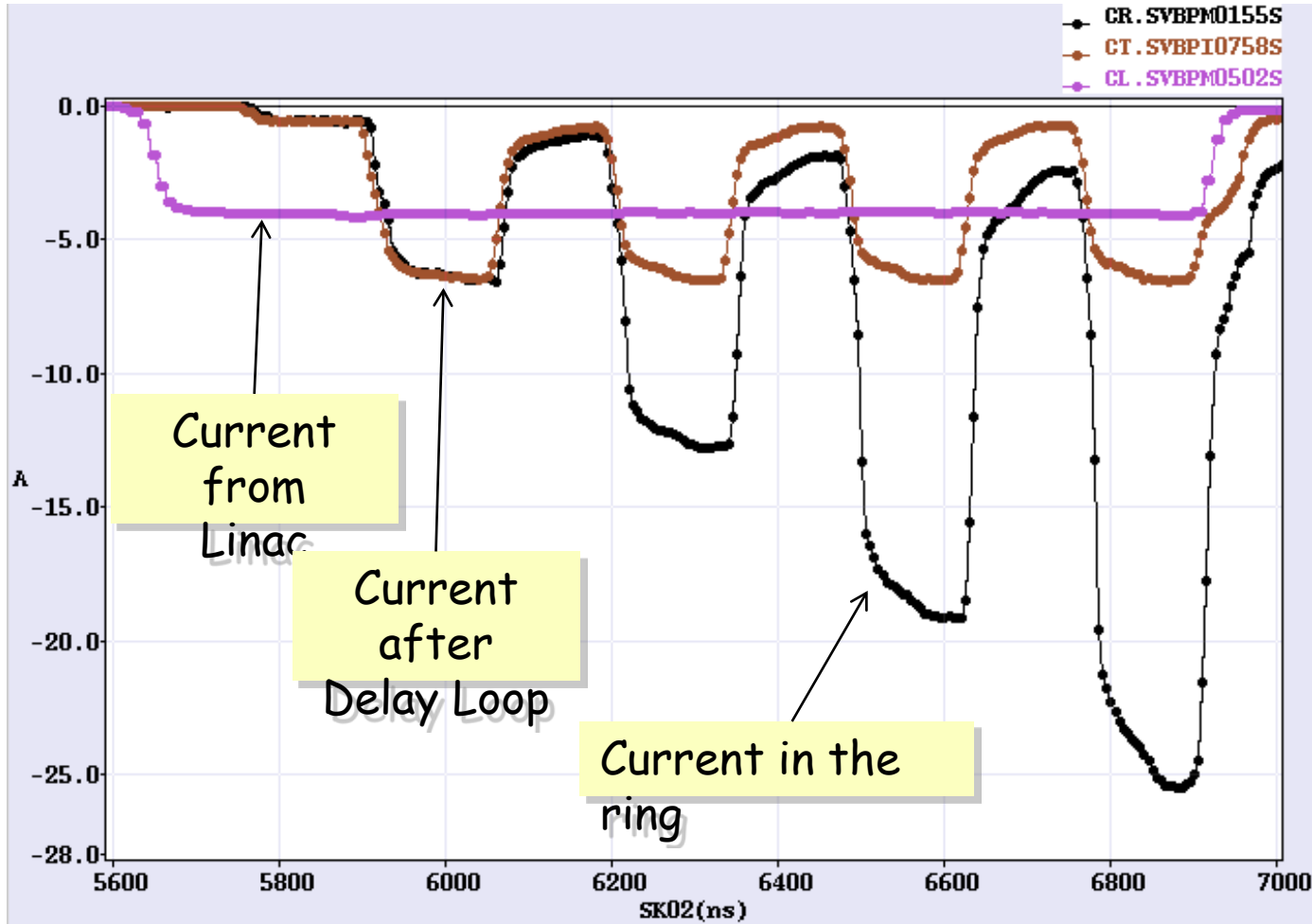
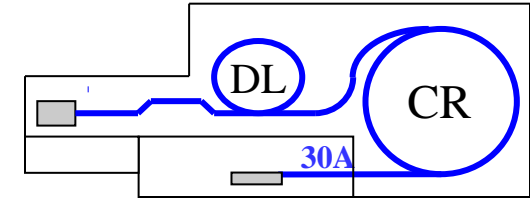


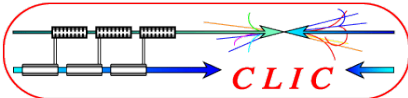


Beam recombination in both rings

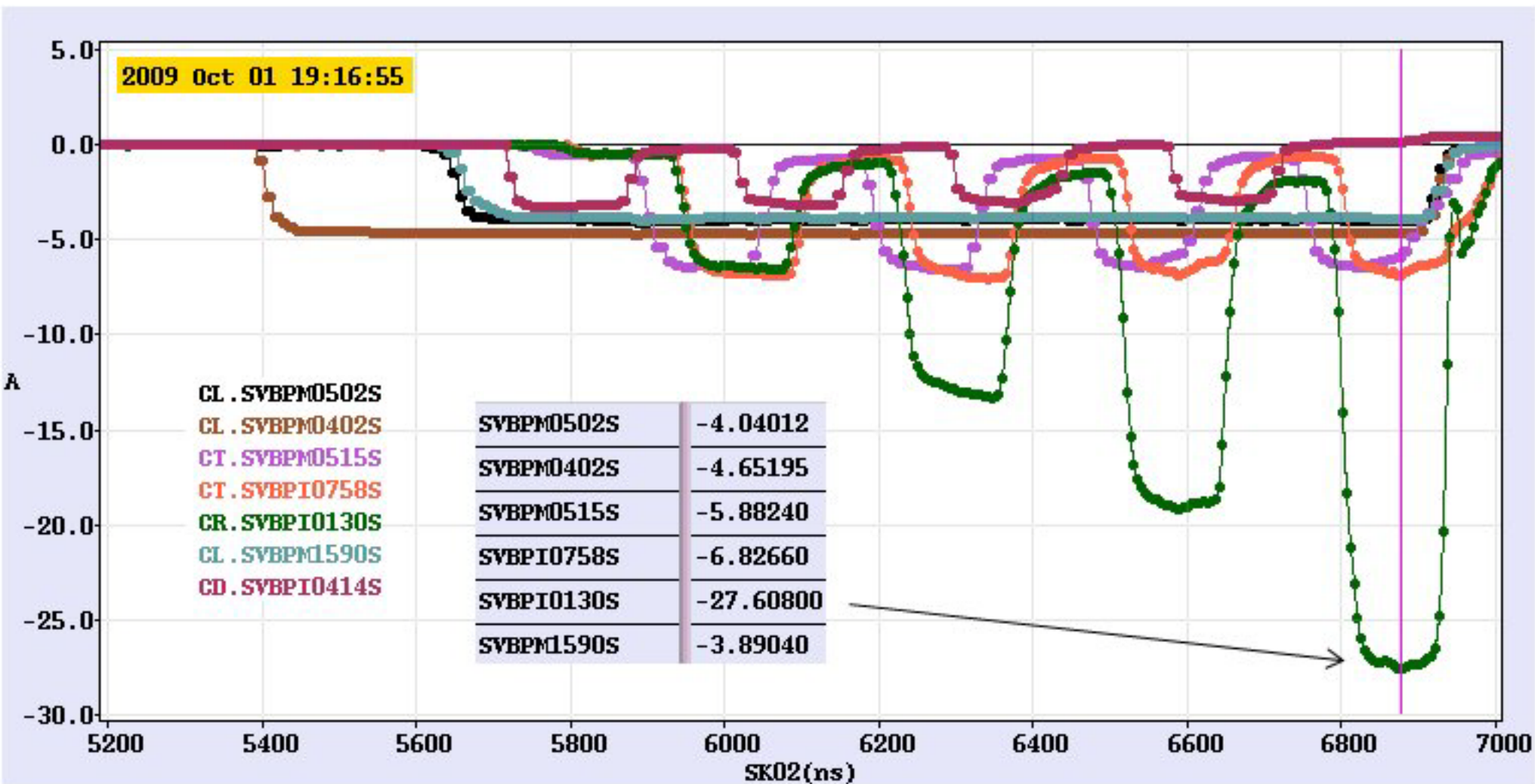


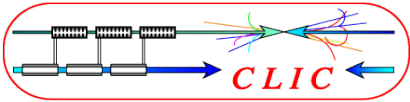
- factor 8 combination achieved with 26 A, 140 ns (Delay Loop + Combiner Ring))



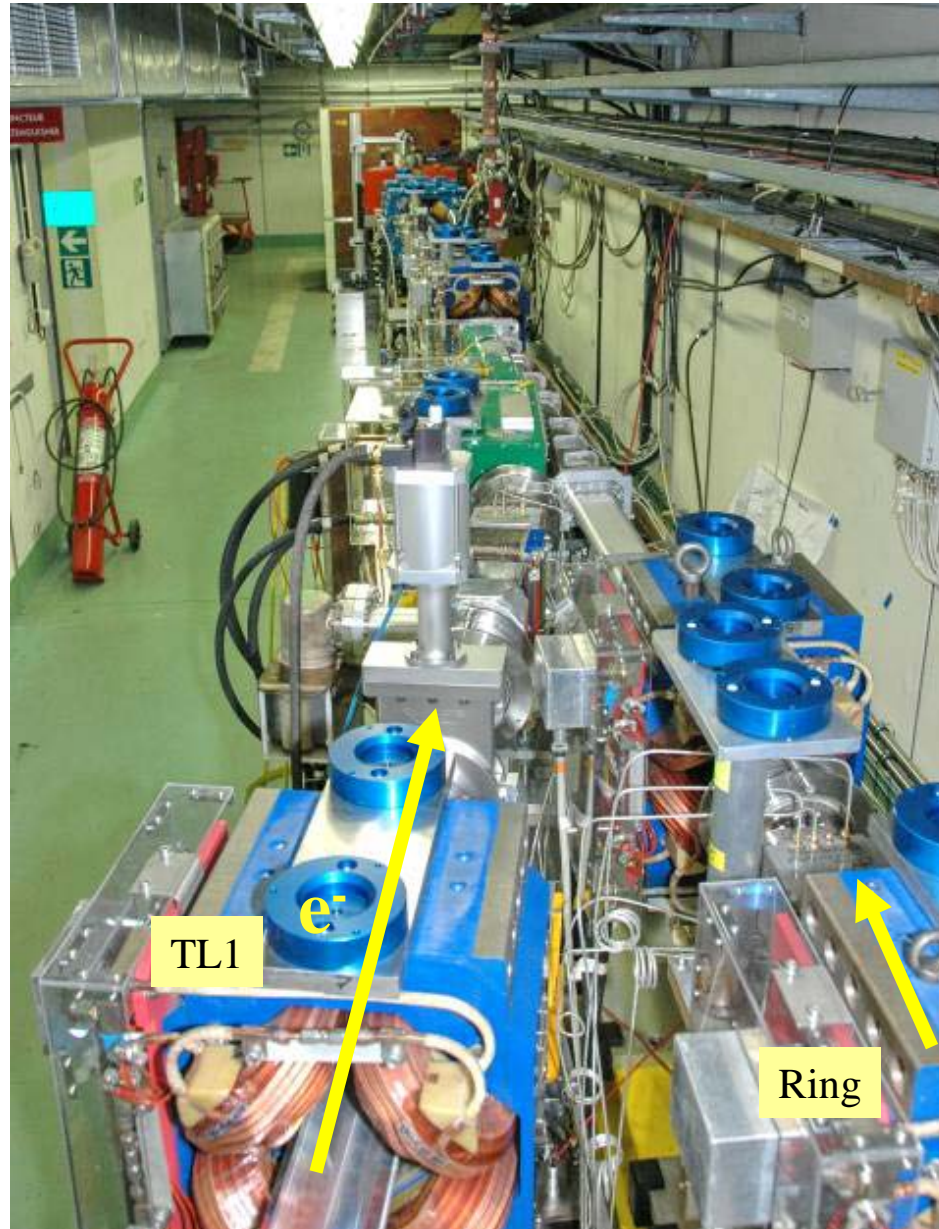
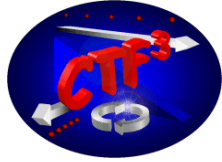


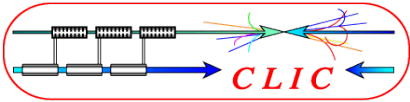
Beam recombination with better pulse shape



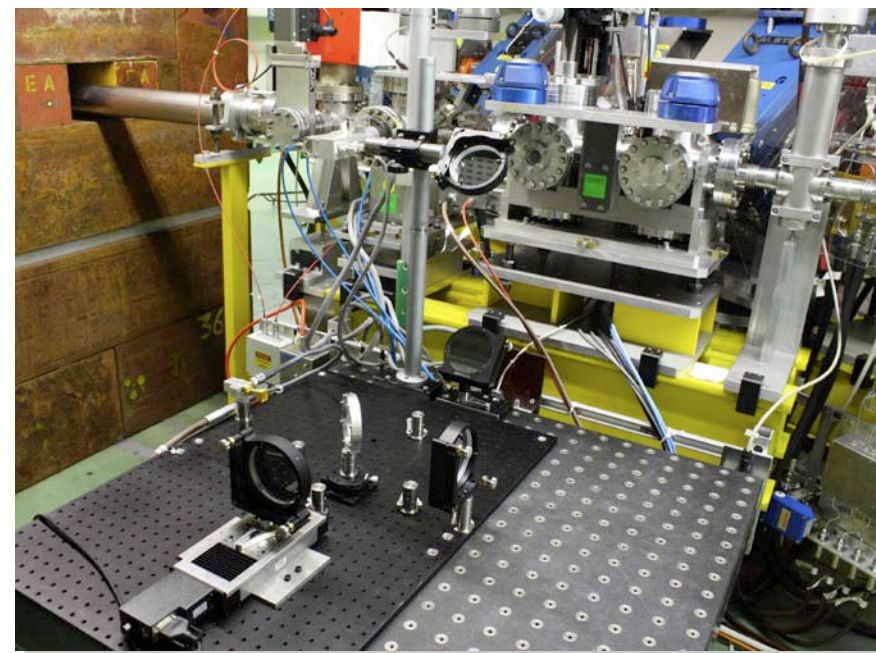
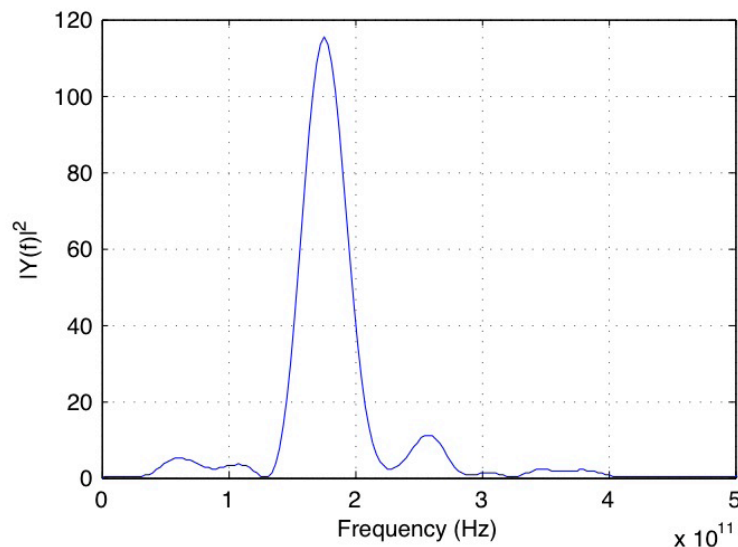
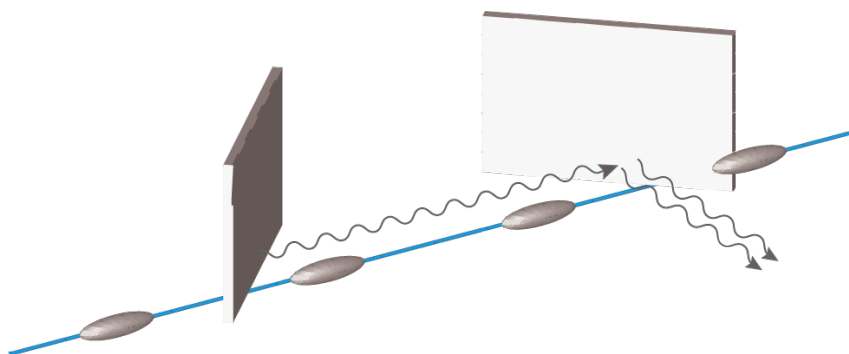


Injection region in the Combiner Ring

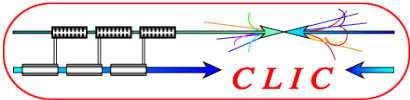




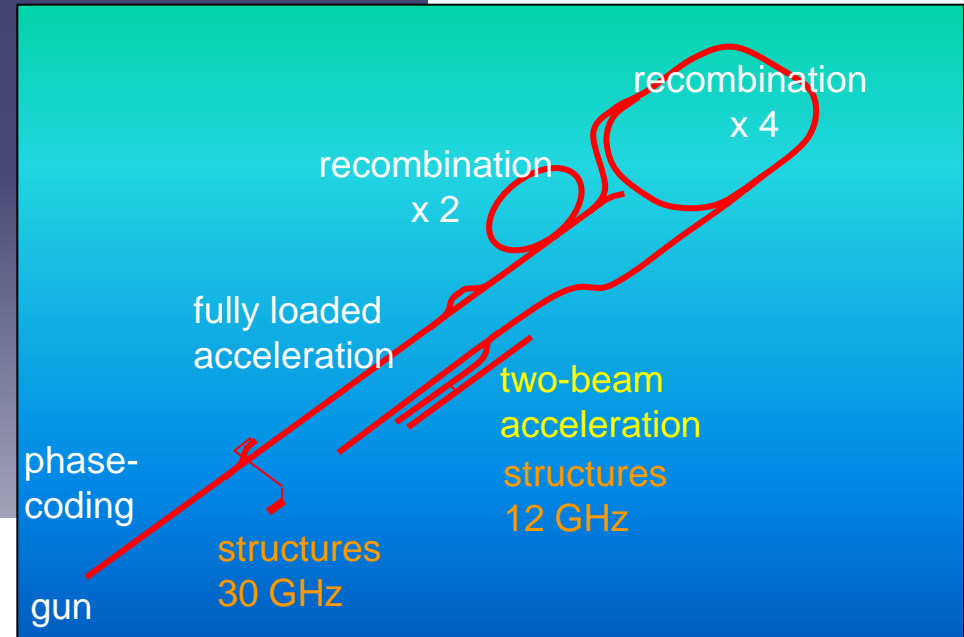
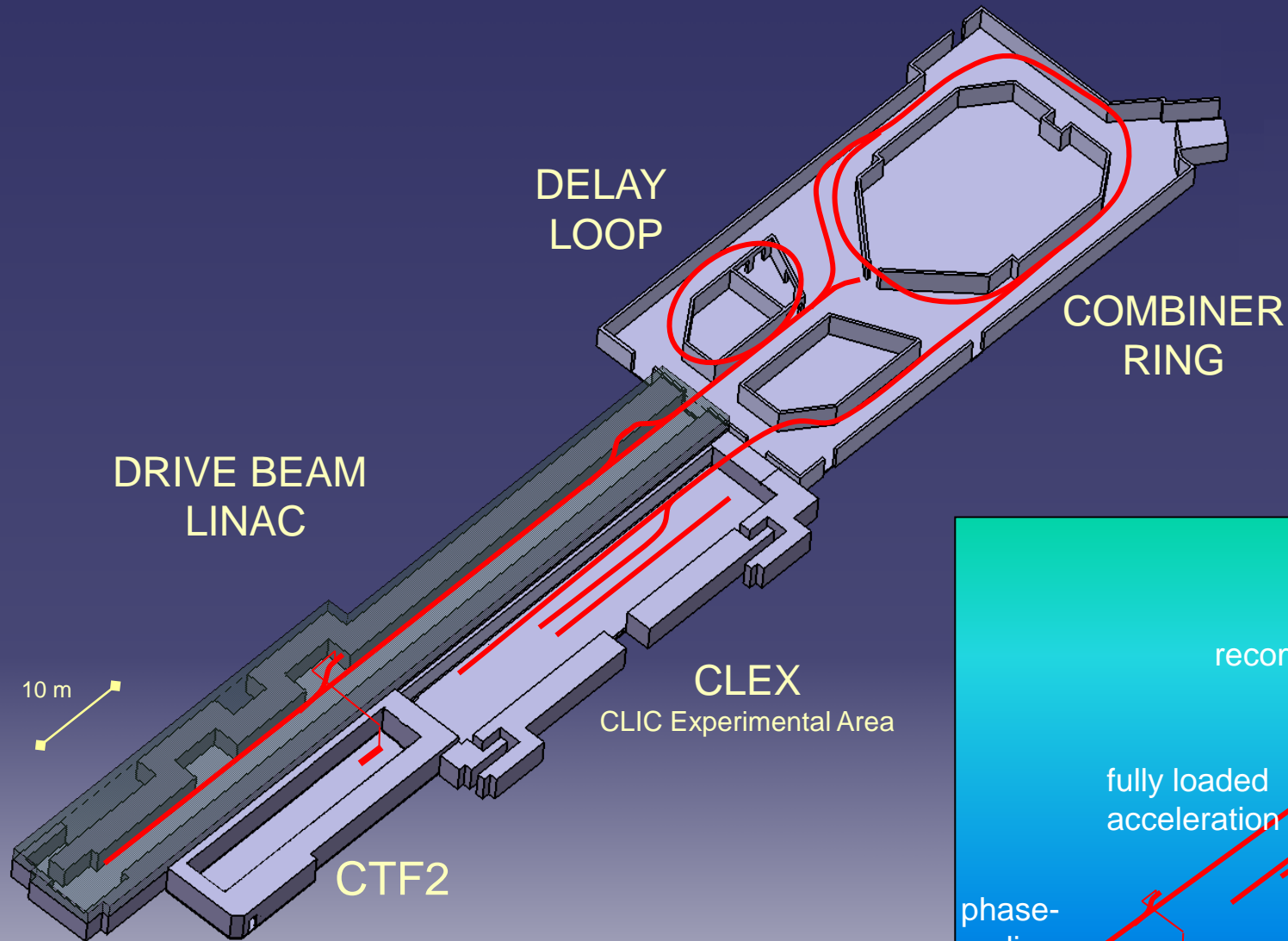
Coherent Diffraction Radiation (CDR) experiment

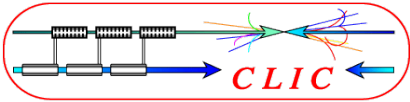


- Diffraction radiation when a charged particle moves close to a medium
- Interferometric measurements extract information on longitudinal beam profile



CTF 3





CLIC - CTF3 infrastructures

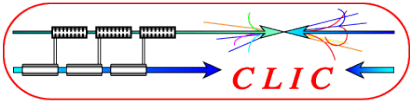


CTF2 hall

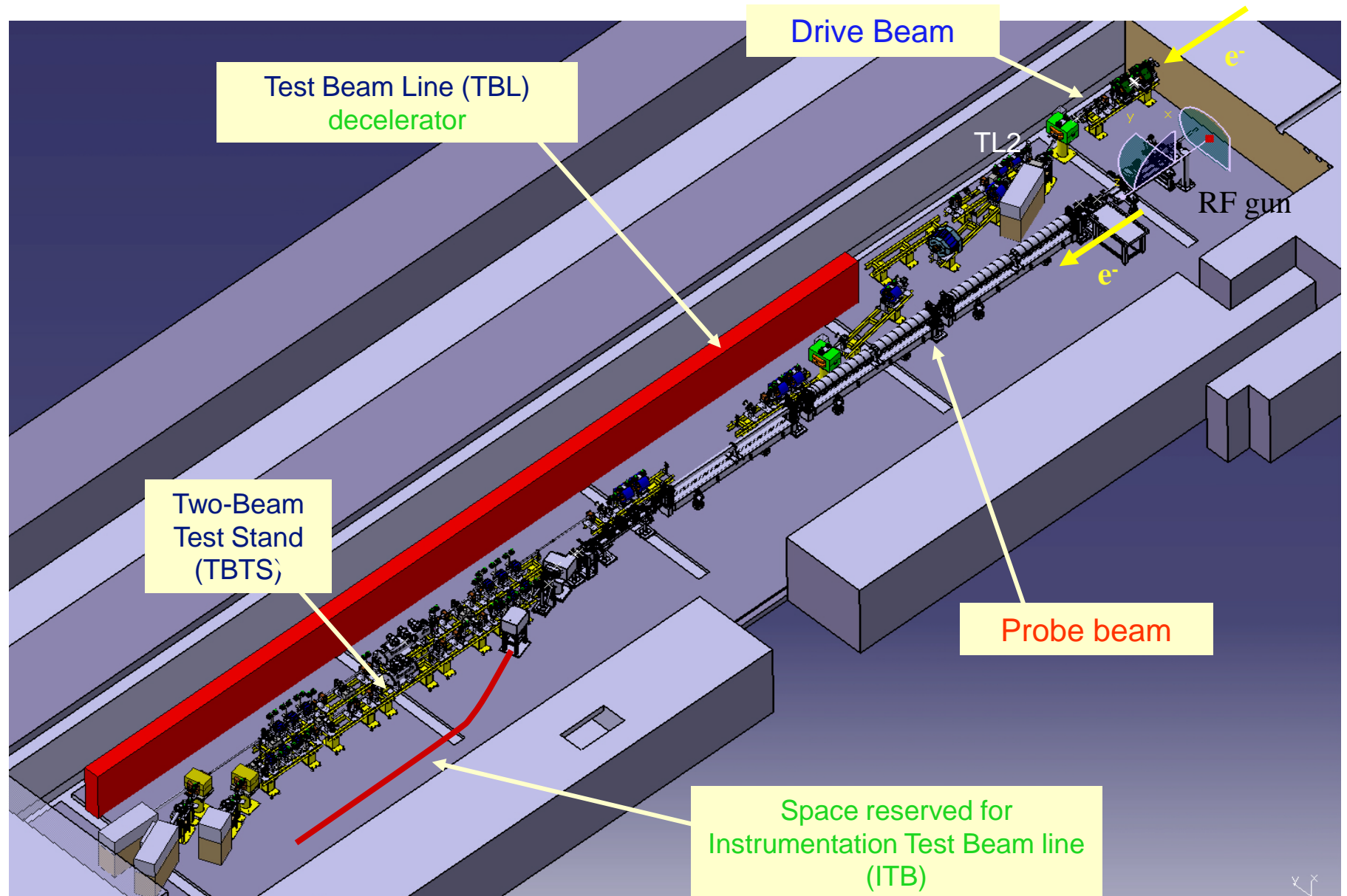
including Photoinjector PHIN

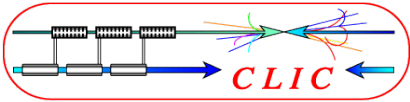
CLEX hall



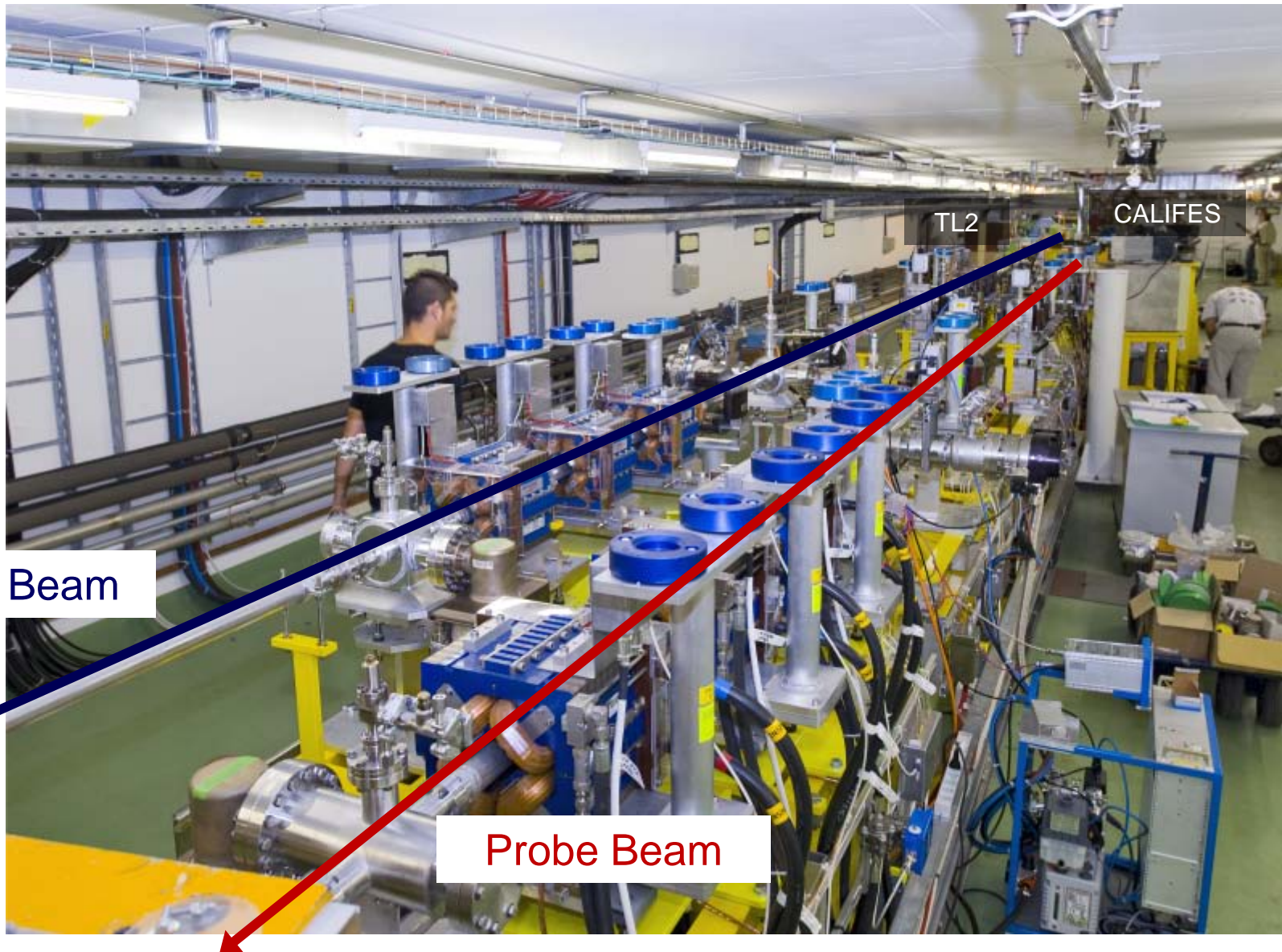


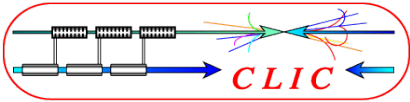
CLEX Layout





Two Beams in CLEX

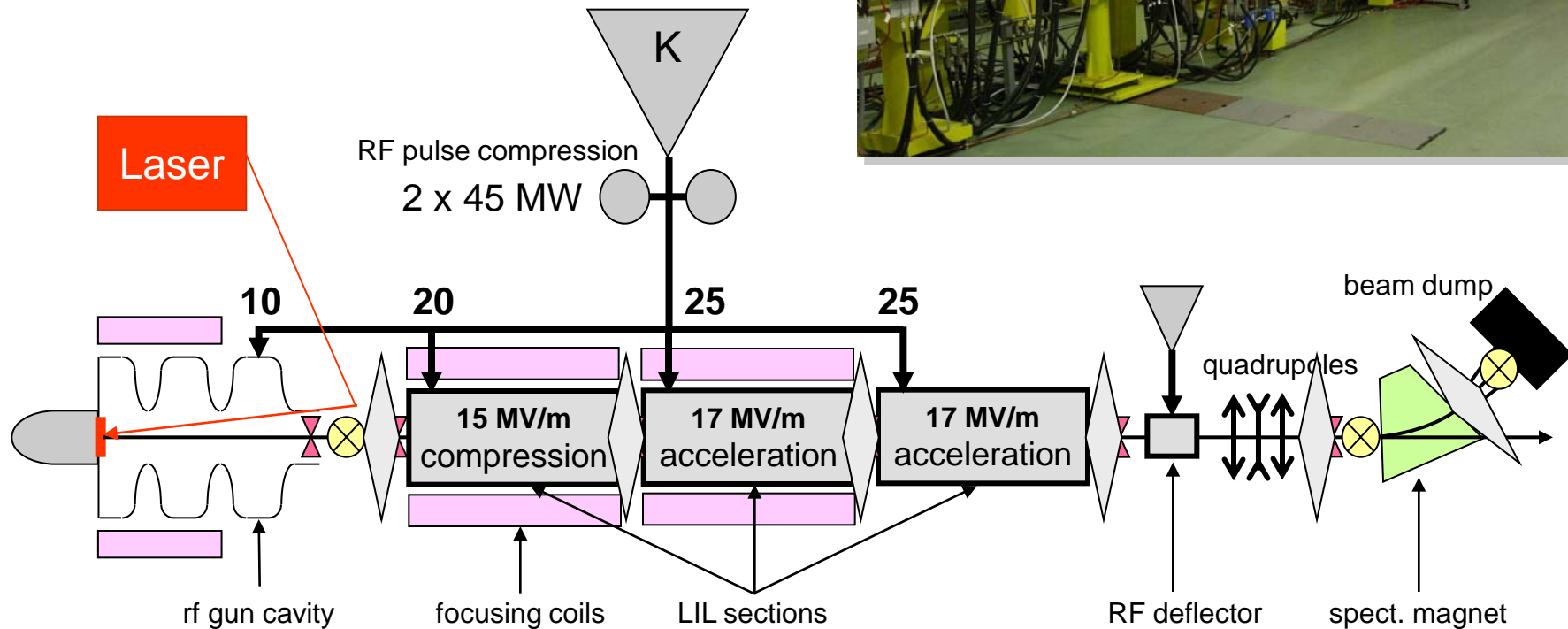
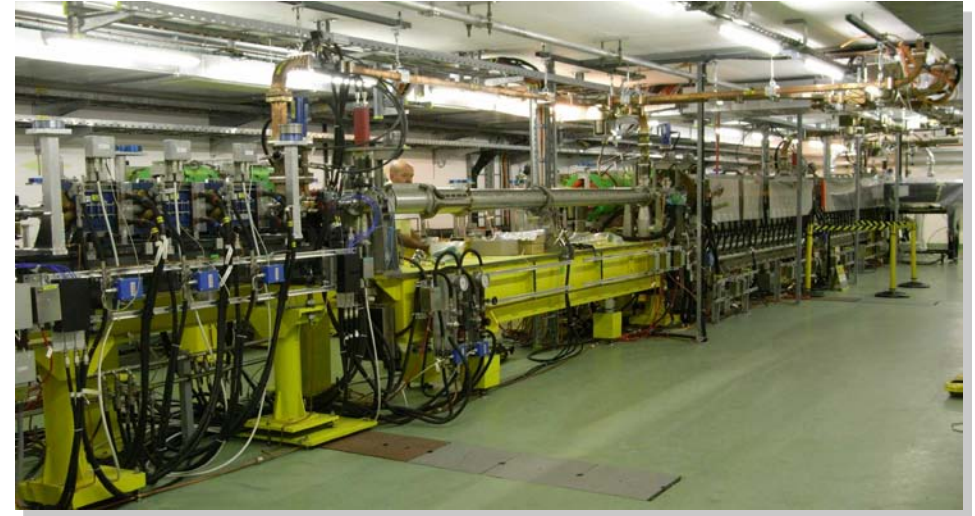




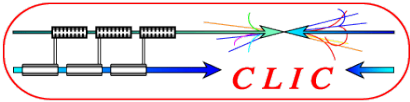
Probe Beam CALIFES



180 MeV
bunch charge 0.6 nC
number of bunches 1 or 32 or 226



CALIFES = Concept d'Accélérateur Linéaire pour Faisceau d'Electrons Sonde
IRFU (DAPNIA), CEA, Saclay, France



Problem with RF deflecting cavity CALIFES ?

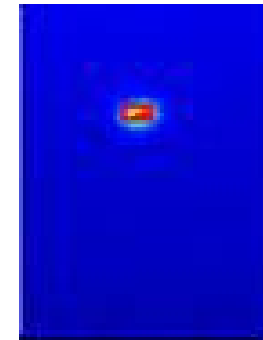


15th May 09: The conditioning of the deflecting RF cavity experiences too high reflected power (-13 dB). After many investigations, we suspected an obstacle in the long waveguide line (~80 m) from the klystron MKS14 to the deflecting cavity.

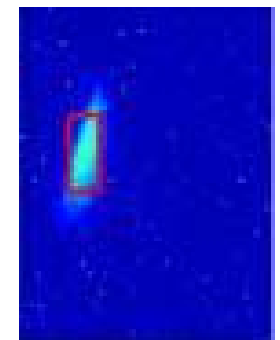
Reflectometric method allows to spot this waveguide.



Object found inside the RF wave guide. It was a device used in the brazing oven

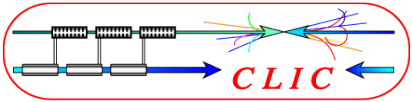


Cavity OFF
 $\sigma_y = 0.24 \text{ mm}$

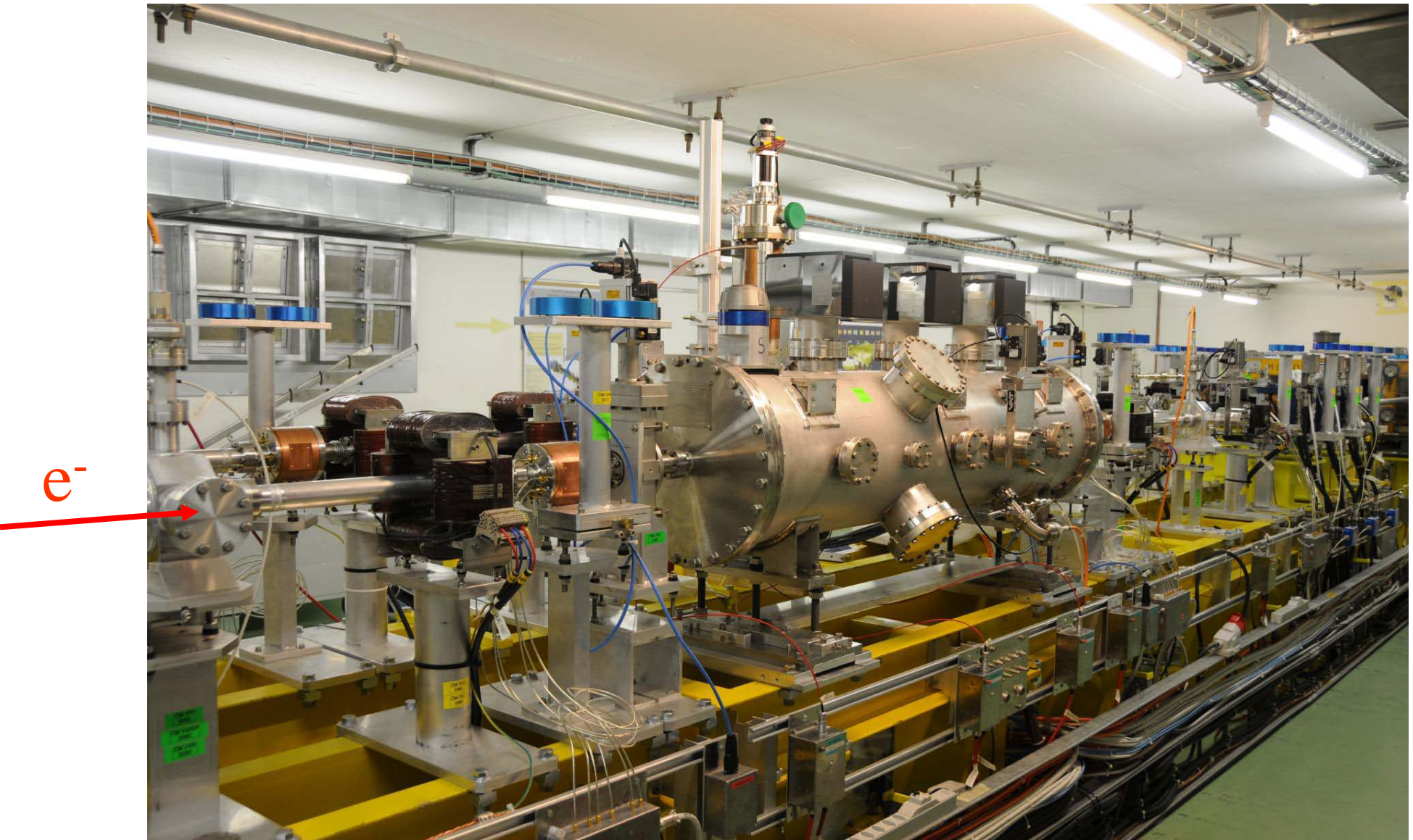


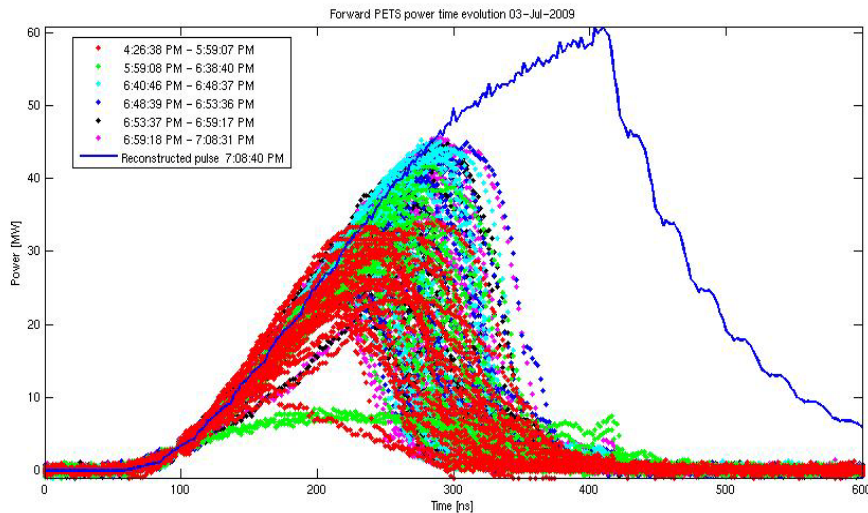
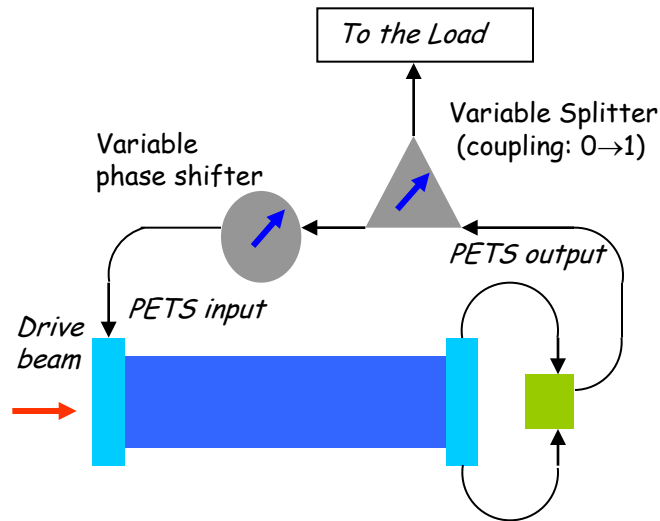
Cavity ON
 $\sigma_y = 1.47 \text{ mm}$

\Rightarrow Electron bunch length $\sigma_t = 1.42 \text{ ps}$
with a laser pulse $\sigma_t = 7 \text{ ps}$



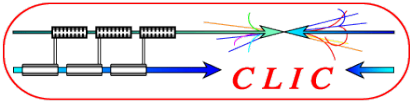
PETS tank on Drive Beam line into CLEX



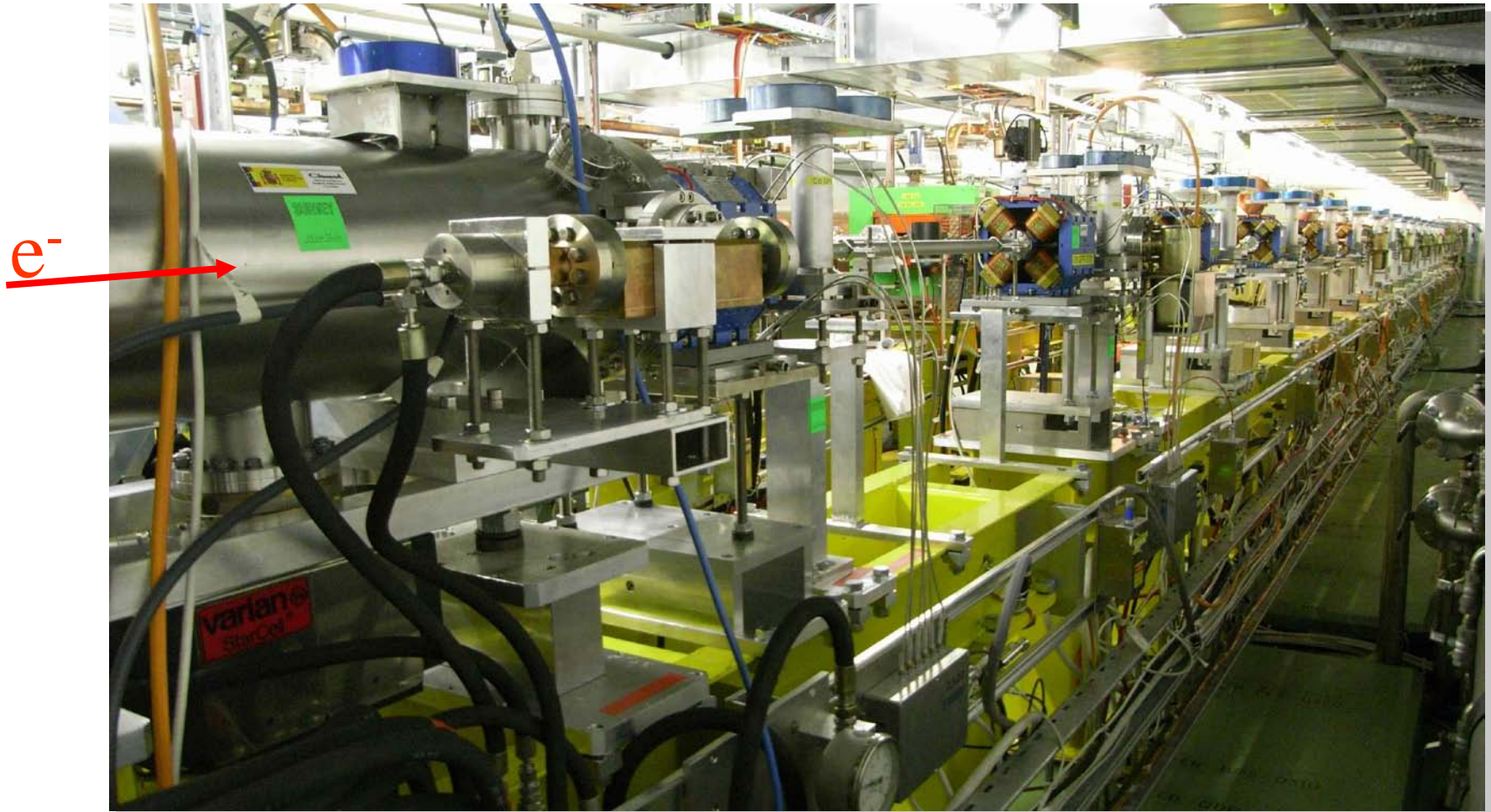


- achieved 125 MW @ 266ns in RF driven test at SLAC
- Max power reached **~140 MW** (peak) with a total pulse length ~ 200 ns at CTF3 (6A e- beam current with recirculation) in TBTS line:

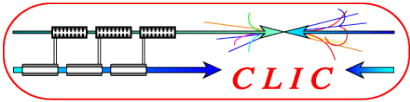
- * no flat top
- * still RF breakdowns



Test Beam Line (TBL) into CLEX hall

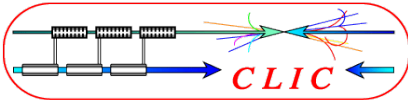


- Beam up to 10 A through PETS ==> 20 MW max produced at a pulse length of 280 ns

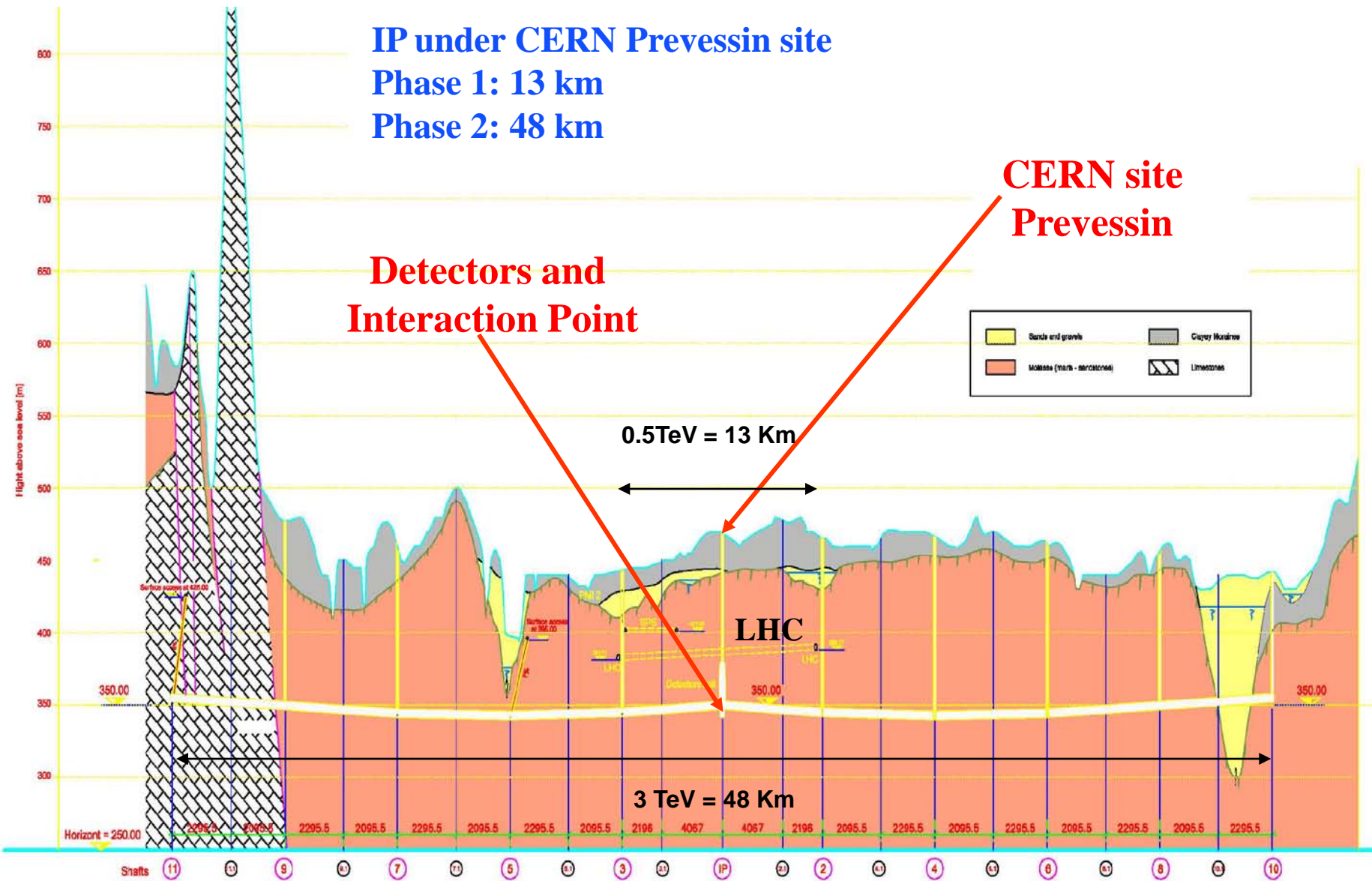


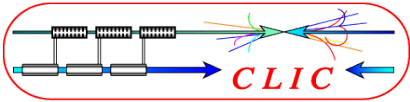
From CTF3 to CLIC

		CTF3	CLIC
Energy	GeV	0.15	2.4
Current	A	32	100
Normalized (geom) emittance	mm mrad	100 (0.3)	100 (0.02)
Pulse length	ns	140	240
train length in linac	μ s	1.2	140
RF Frequency	GHz	3	1
Compression factor		2 x 4	2 x 3 x 4



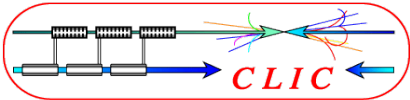
Longitudinal section on CERN site





Between Jura and Lemman lake

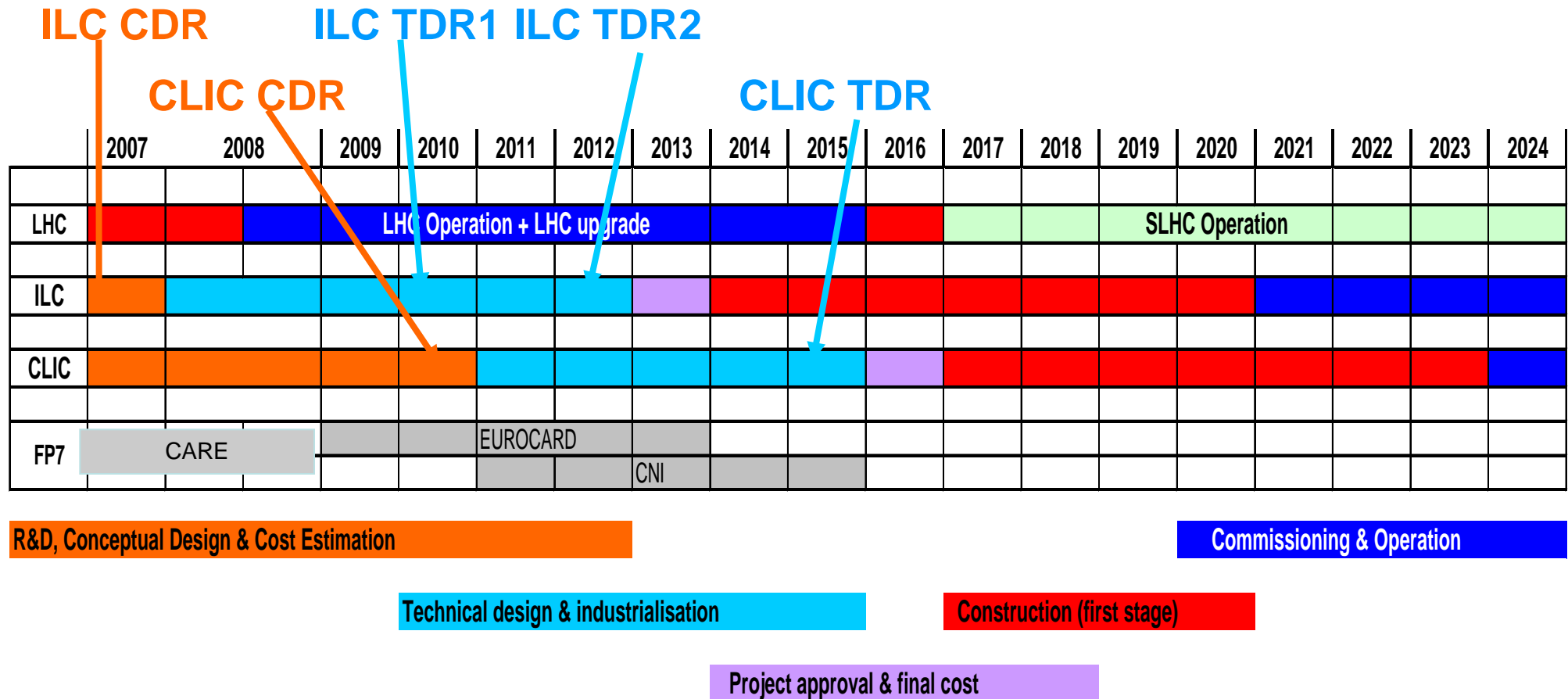


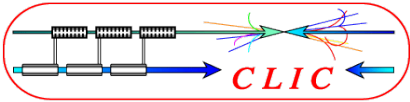


CLIC in HEP context



Complementary to LHC

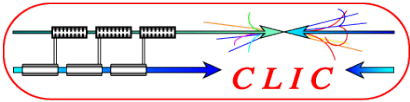




B. Barish / GDE

Last week at the
CLIC09 workshop

- The central frontier of particle physics is and will continue to be the energy frontier!
- The LHC will open a new era at that frontier and its discoveries will motivate the next machine --- a lepton collider.
- That machine could be the ILC or CLIC (or maybe a muon collider). Science must dictate the choice of machines, informed by the realities of technical performance, readiness, risk and cost for each option.
- It is our jobs (ILC and CLIC design teams) to make sure our R&D and design work will enable the best informed decision for our field.



Conclusion



CLIC technology is **today the only** possible scheme to extend Linear Collider into Multi-TeV energy range

Although very promising results have been achieved with the various tests facilities, CLIC technology is **not yet mature**

Novel ideas are necessary in order to tackle the challenging CLIC R&D

The world-wide collaboration is certainly a major asset

A CLIC Conceptual Design Report (CDR) with cost estimate is expected **by 2010** and a Technical Design Report (TDR) **by 2015**

**Your participation is warmly welcome
to the CLIC and ILC studies**