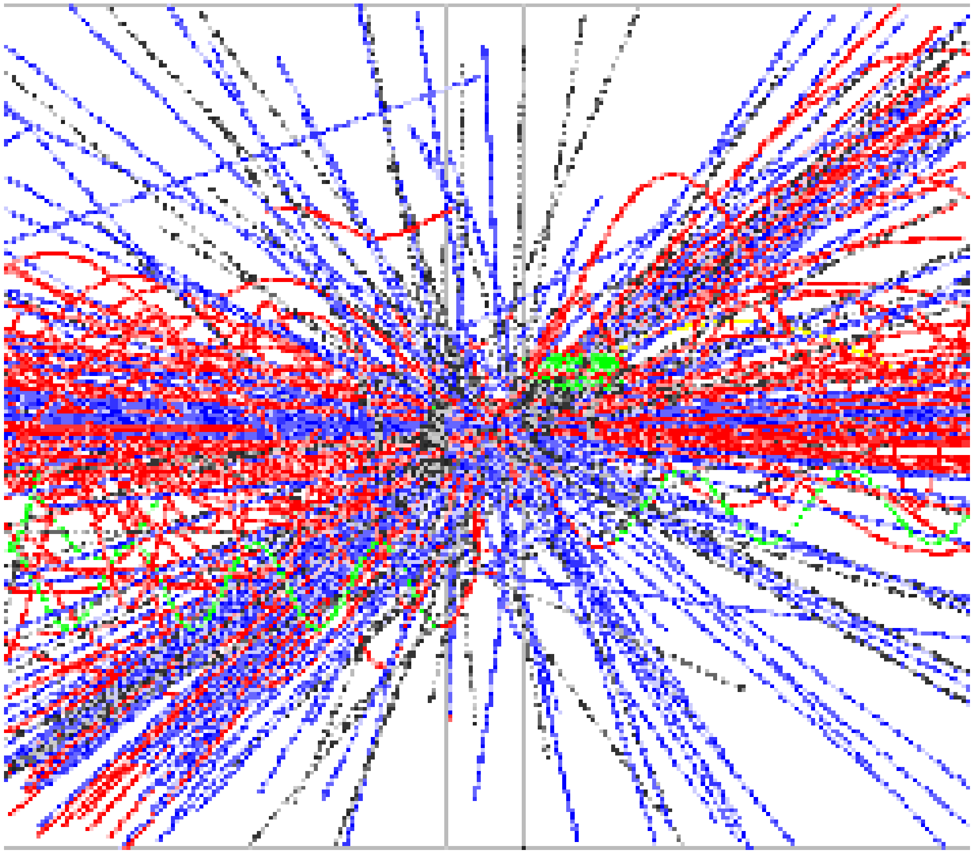
Possible future $e^+ e^-$ linear colliders

with special emphasis on CLIC

Louis Rinolfi / CERN

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

ILC expectation:

ILC nominal energy study is 0.5 TeV.
However the present design is done in order to run up to 1 TeV

CLIC expectation:

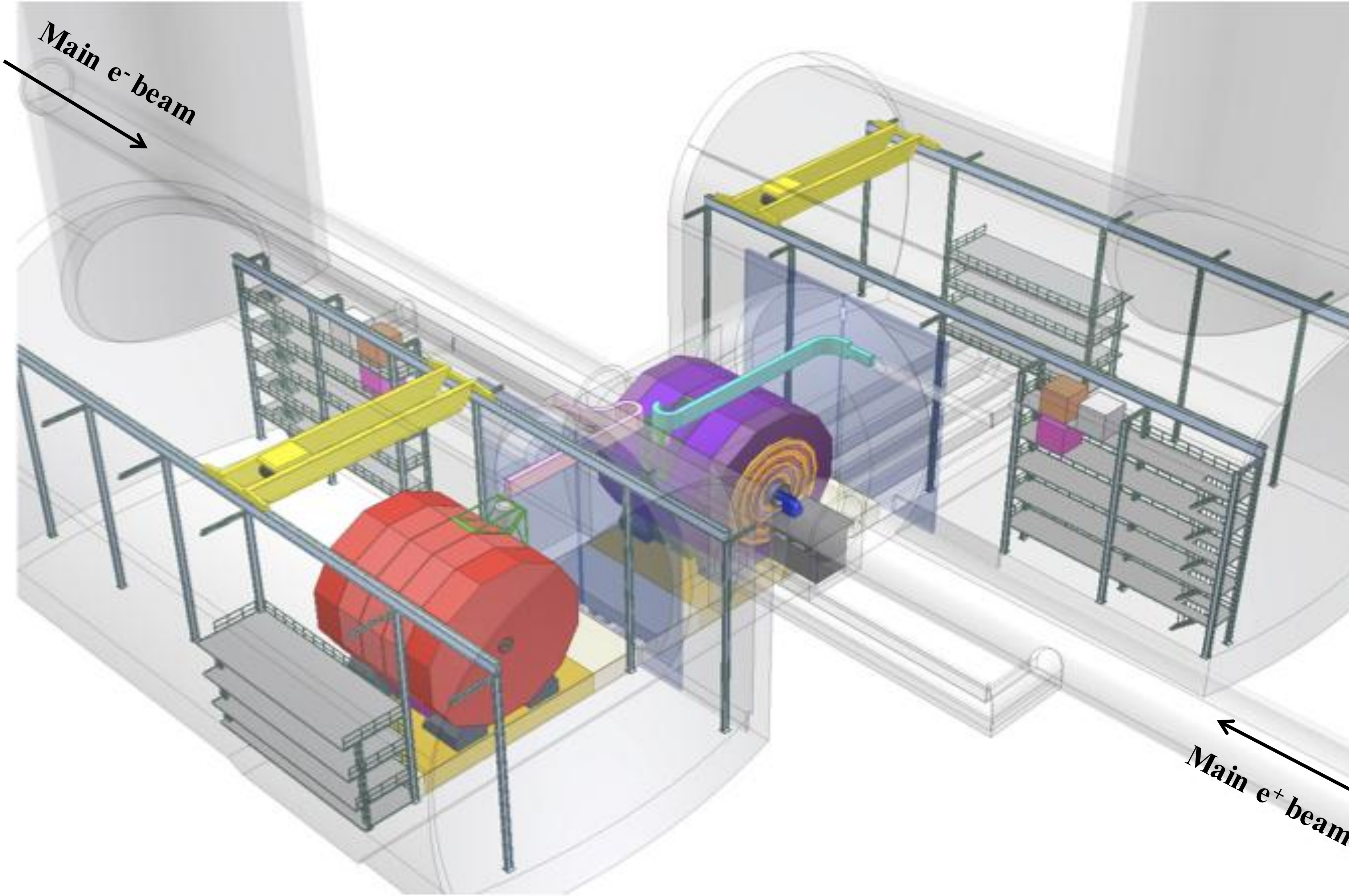
CLIC nominal energy study is 3 TeV.
However the present design is done in order to run over a wide energy range: 0.5 to 3 TeV
(studies have been performed up to 5 TeV).

K. Peach / JAI

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

Push Pull detectors



A very short history for CLIC

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)

2011: Demonstration of beam acceleration at 12 GHz with gradient 100 MV/m

2012: **Publication of the Conceptual Design Report (CDR)**

More than 27 years !!!

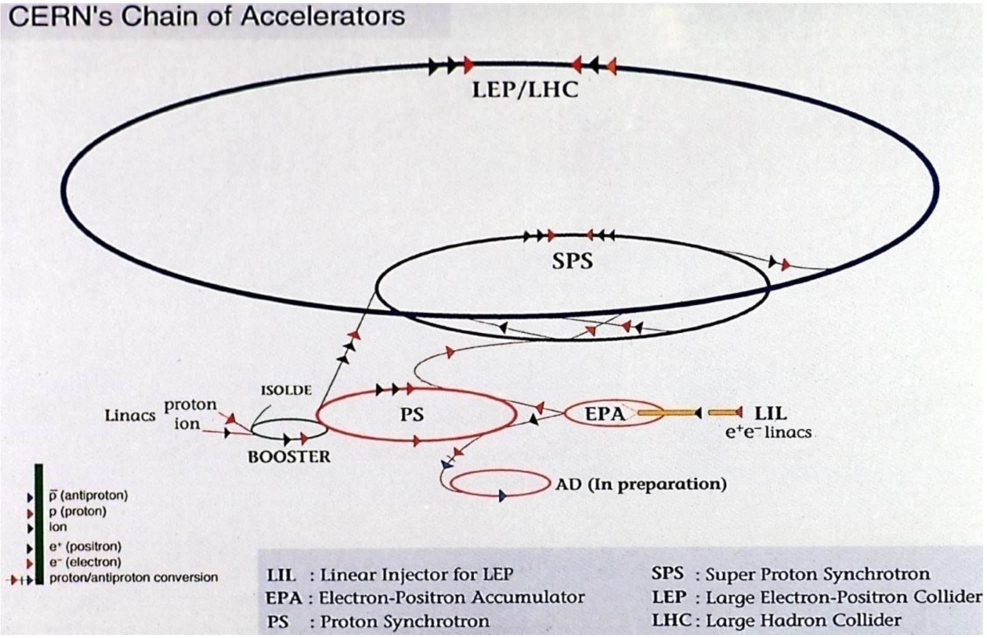
Present R&D proceeds with the following requirements:

- *Energy center of mass* E_{CM} = **0.5 - 3 TeV**, and beyond
- *Luminosity L* > few **10^{34} cm^{-2} s^{-1}** with acceptable background and energy spread
- Design should be compatible with a maximum *length* ~ **50 km**
- Total power consumption < **300 MW**
- Affordable (CHF, €, $, £,……)

Present goal:

Demonstrate all key feasibility issues and write a Conceptual Design Report (CDR)
Publication foreseen in March 2012

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

The International Collaboration

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

World-wide CLIC&CTF3 Collaboration

41 Institutes from 21 countries

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

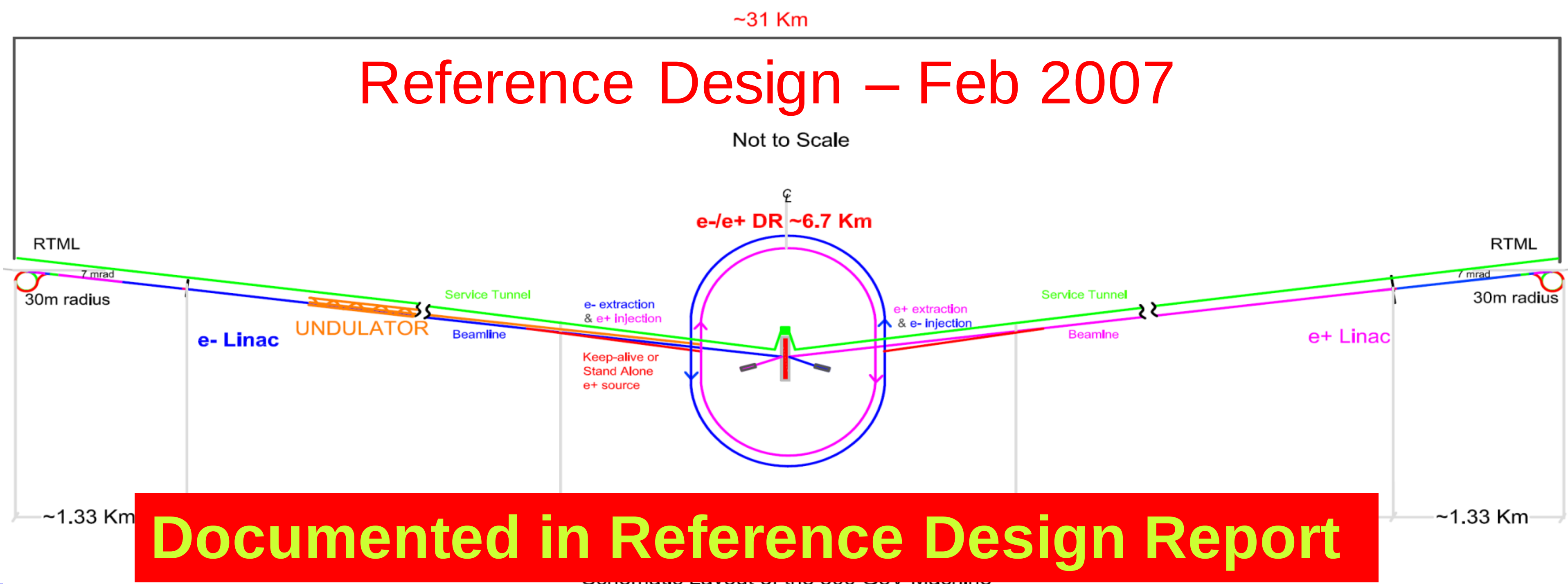
Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
IHEP (China)
INFN / LNF (Italy)
Instituto de Fisica Corpuscular (Spain)
IRFU / Saclay (France)
Jefferson Lab (USA)
John Adams Institute/Oxford (UK)

John Adams Institute/RHUL (UK)
JINR (Russia)
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NIKHEF/Amsterdam (Netherland)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Patras University (Greece)

Polytech. University of Catalonia (Spain)
PSI (Switzerland)
RAL (UK)
RRCAT / Indore (India)
SLAC (USA)
Thrace University (Greece)
Tsinghua University (China)
University of Oslo (Norway)
Uppsala University (Sweden)
UCSC SCIPP (USA)

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



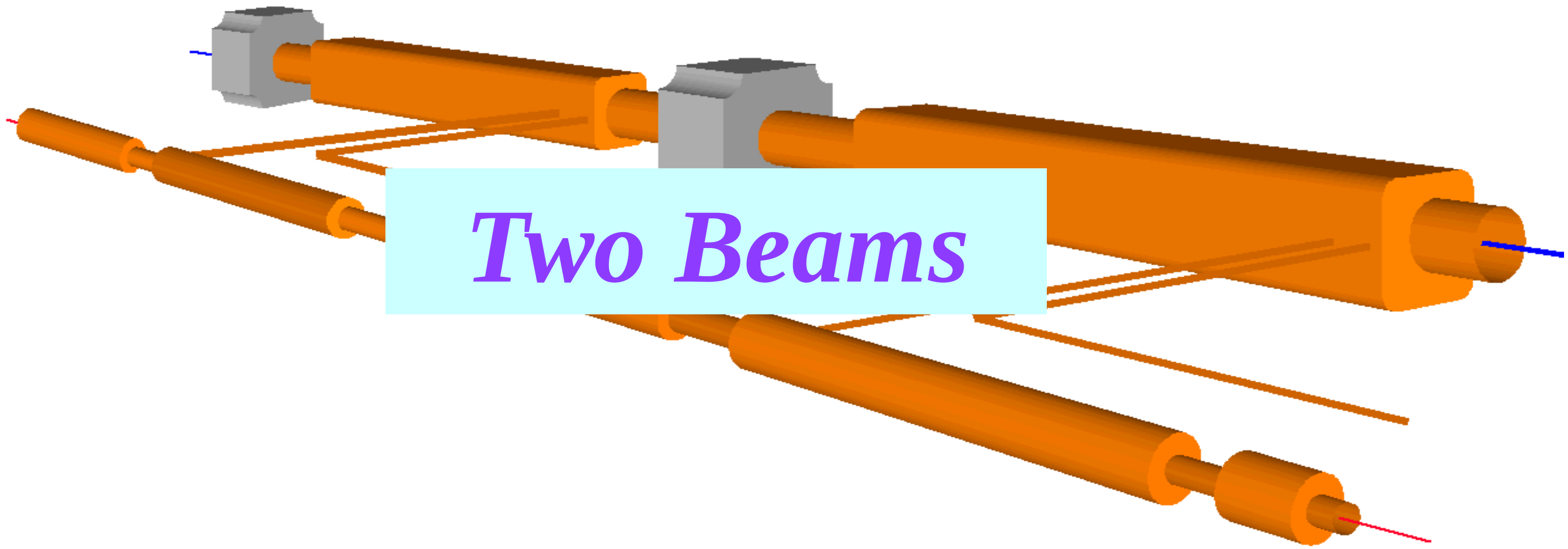
Documented in Reference Design Report

ILC/CLIC Collaboration Working Groups

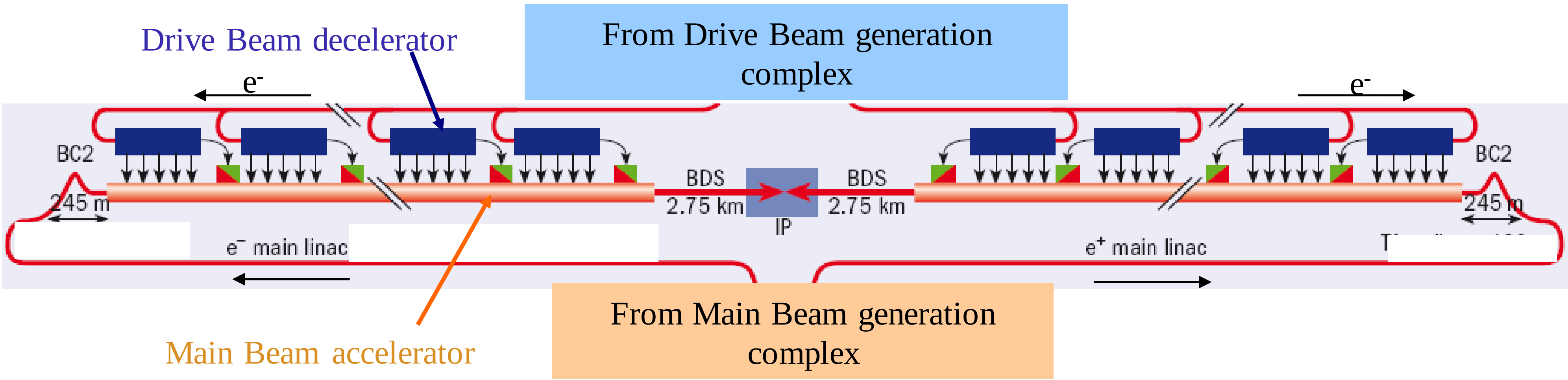
	CLIC	ILC
Physics & Detectors	L.Linssen, D.Schlatter	F.Richard, S.Yamada
Beam Delivery System (BDS) & Machine Detector Interface (MDI)	L.Gatignon, D.Schulte, R.Tomas Garcia	B.Parker, A.Seriy
Civil Engineering & Conventional Facilities	J.Osborne.	V.Kuchler
Positron Generation	L.Rinolfi	W. Gai
Damping Rings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

9 common working groups

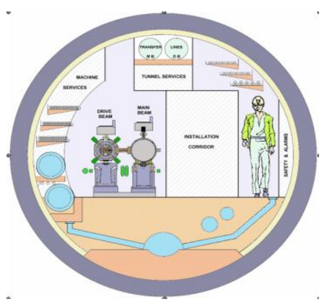
The Two Beams Concept



The basic layout for a Two-Beam scheme

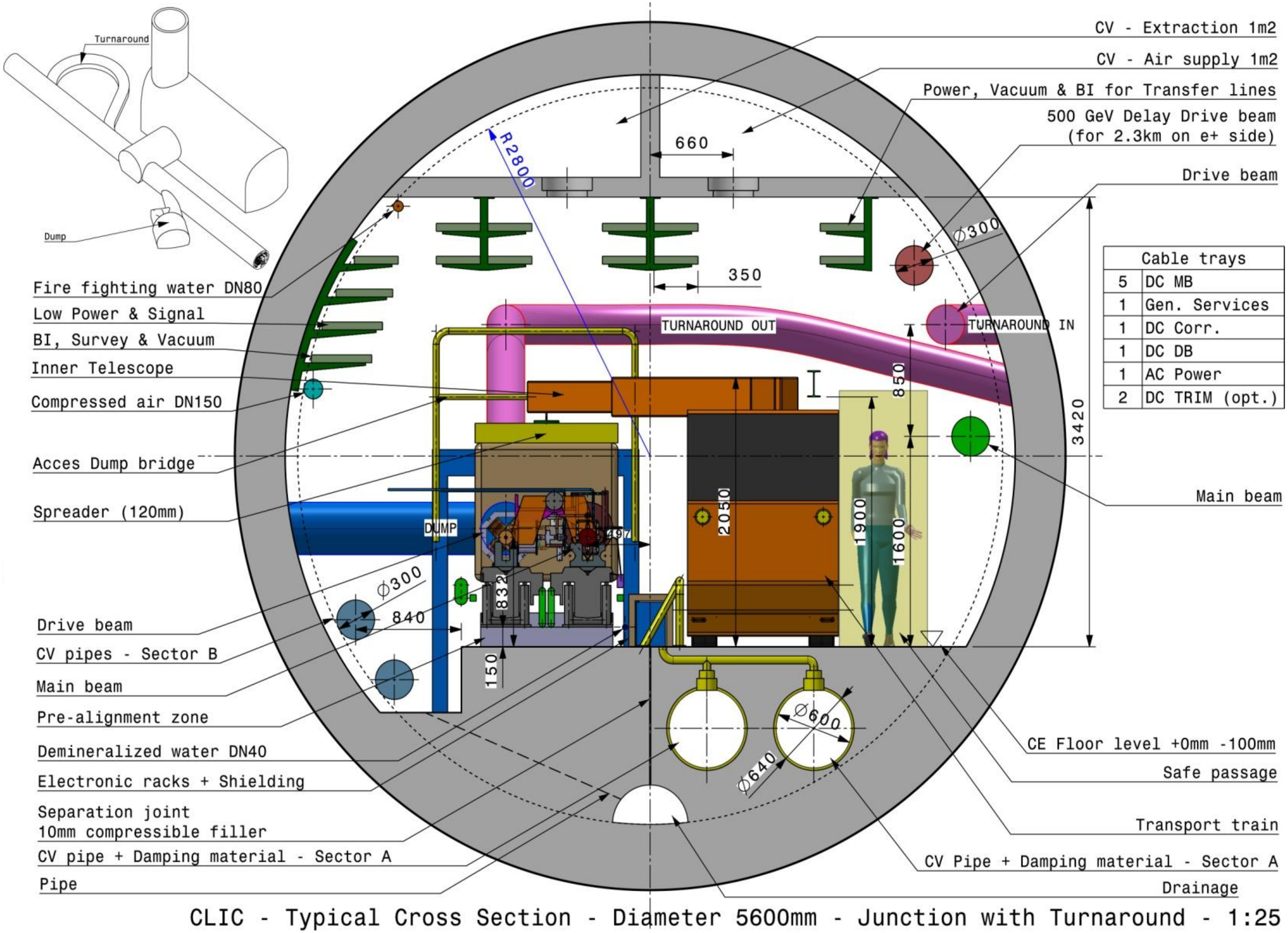


- **High acceleration gradient and high frequency**
  - "Compact" collider
  - Normal conducting accelerating structures

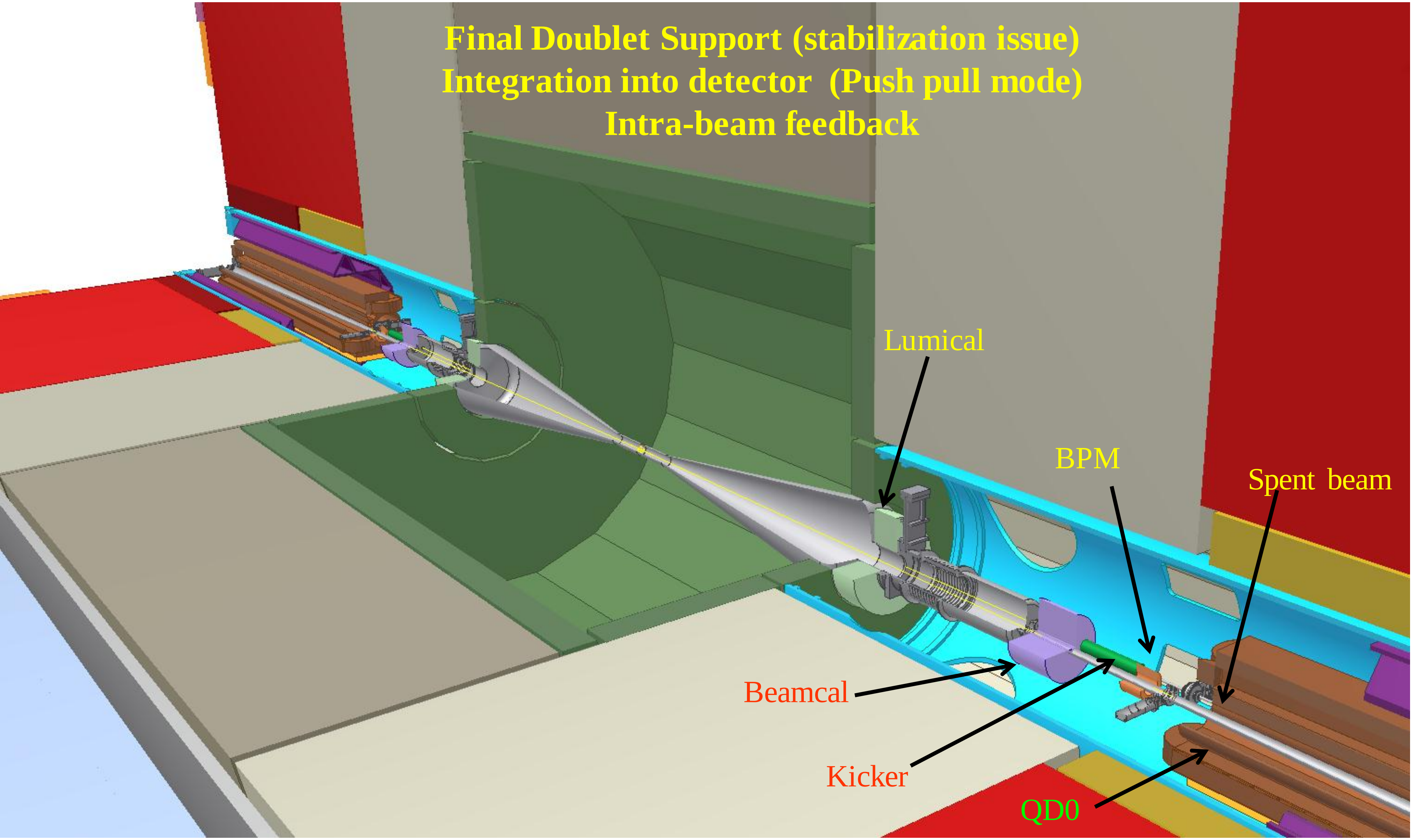


- **Two-Beam Acceleration Scheme**
  - Simple tunnel, no active elements
  - Modular, easy energy upgrade in stages

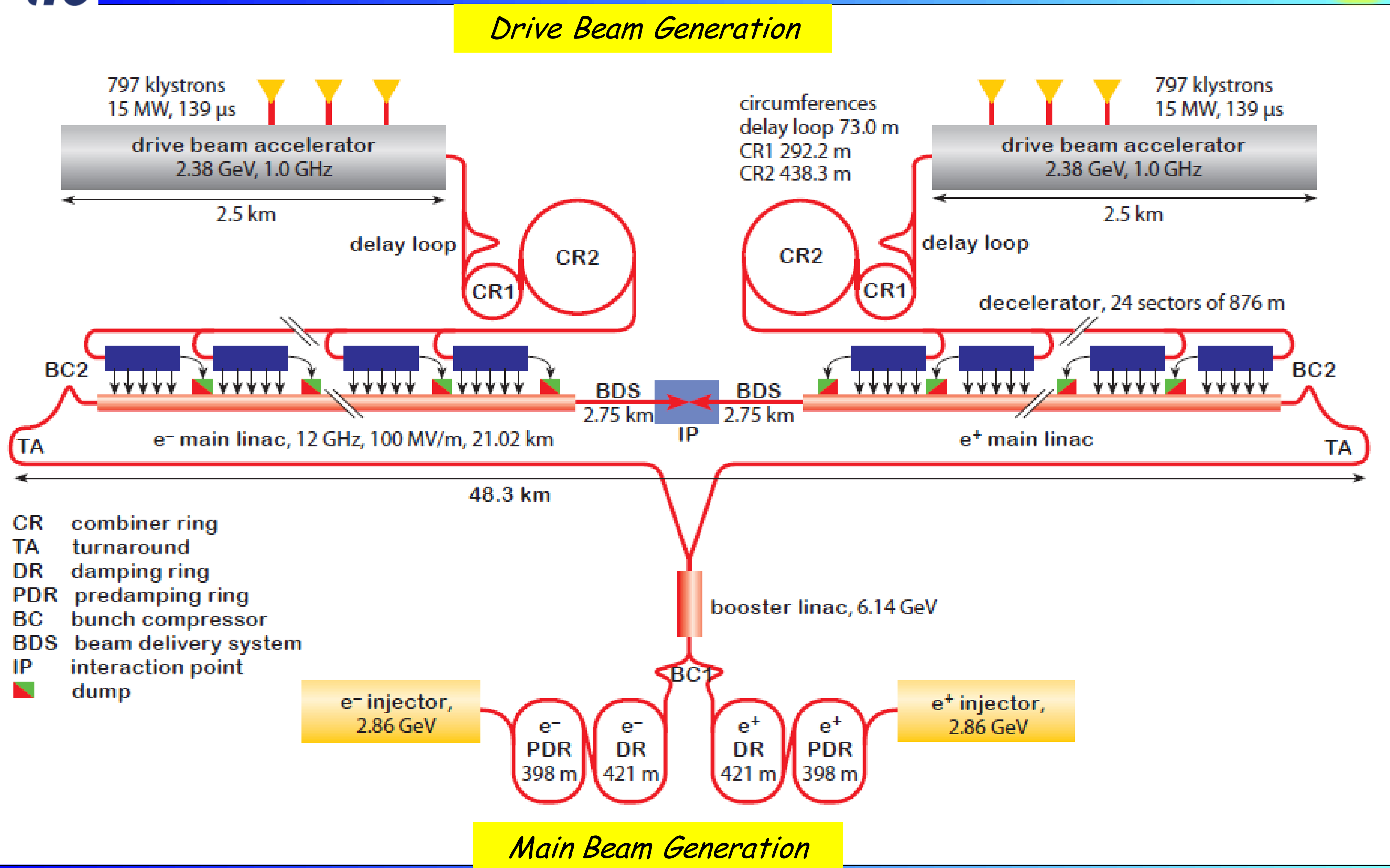
The CLIC tunnel in February 2011 (ϕ = 5.6 m)



A. Hervé / ETH Zurich

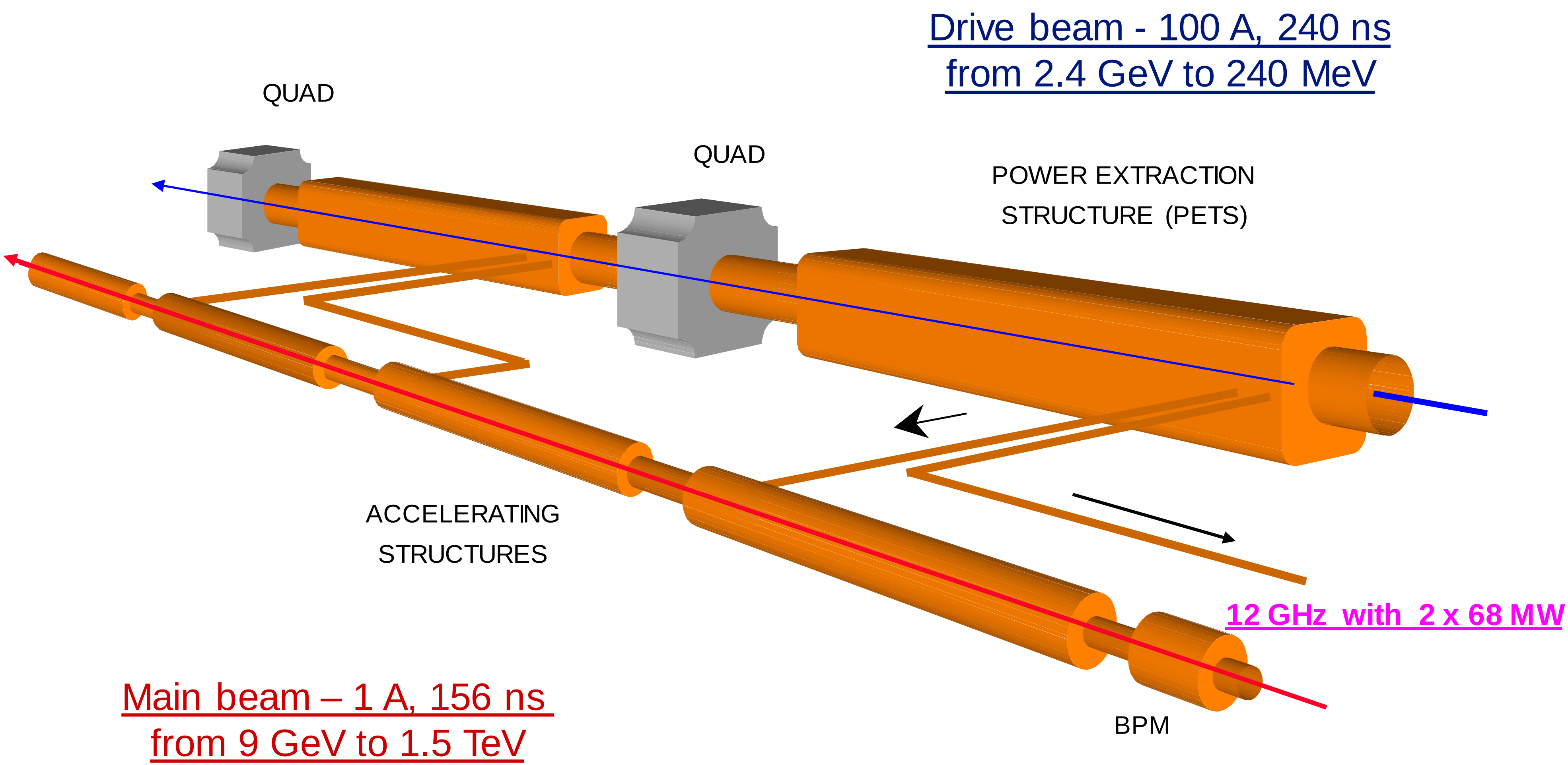


General CLIC layout for 3 TeV

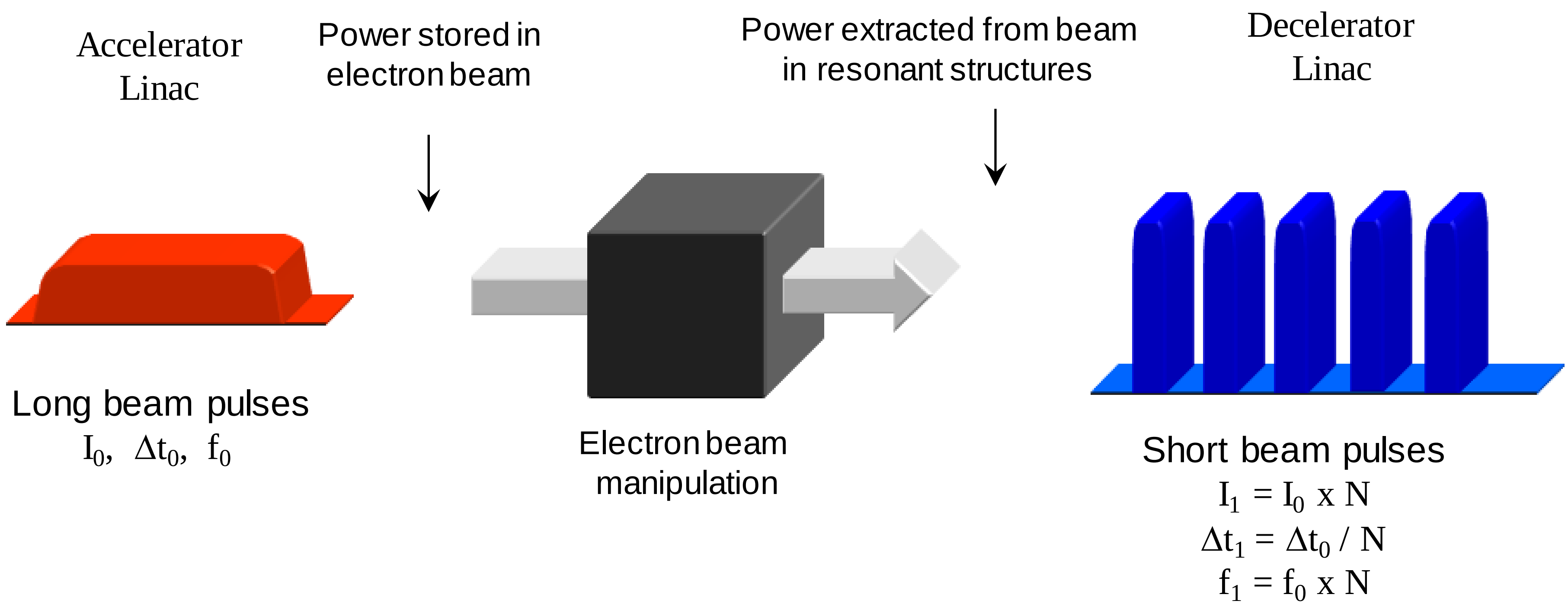


CLIC nominal parameters at I.P.

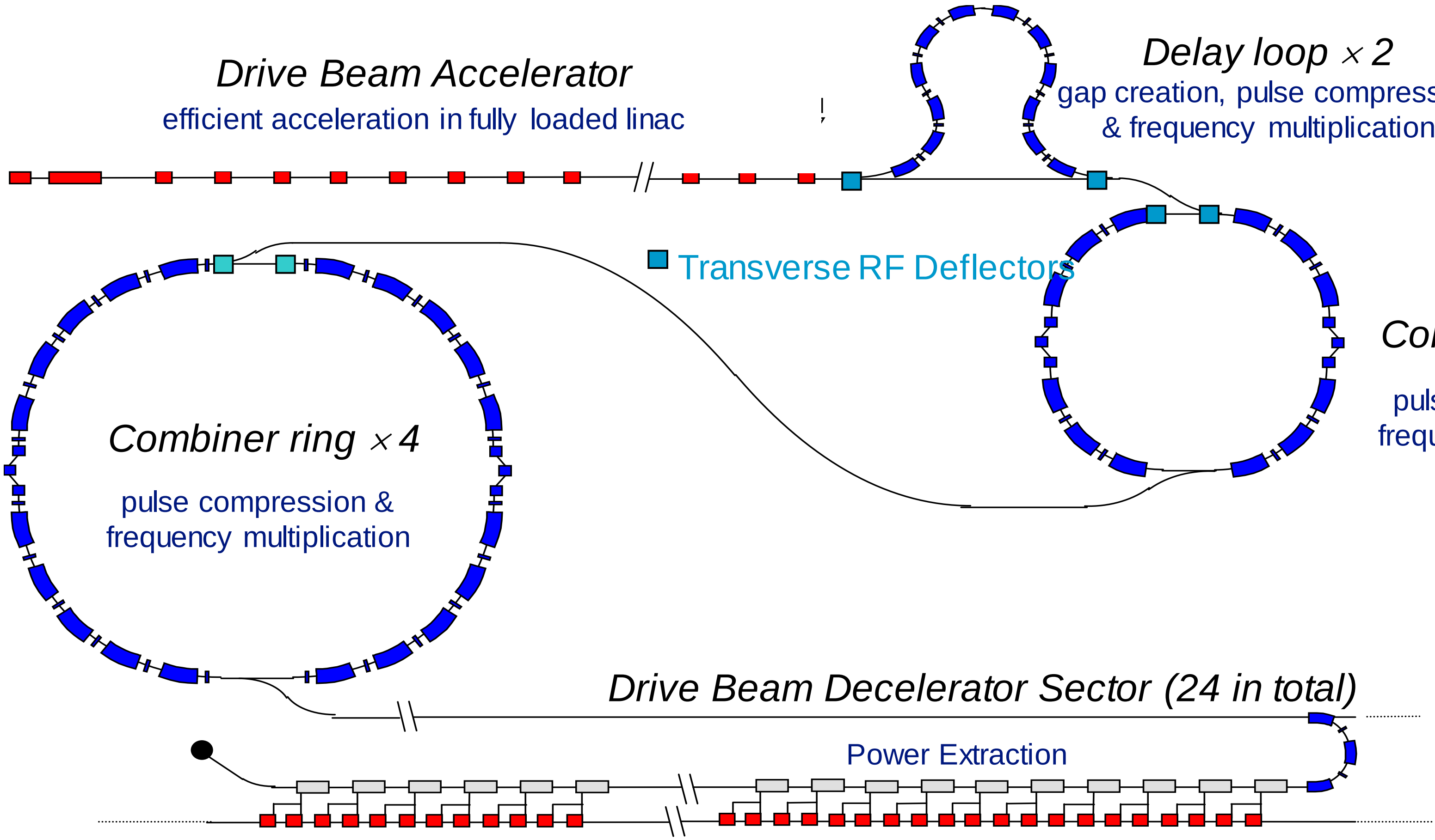
Center-of-mass energy	CLIC 500 GeV		CLIC 3 TeV	
Beam parameters	Relaxed	Nominal	Relaxed	Nominal
Total (Peak 1%) luminosity ($cm^{-2}.s^{-1}$)	$8.8 (5.8)\cdot10^{33}$	$2.3 (1.4)\cdot10^{34}$	$7.3 (3.5)\cdot10^{33}$	$5.9 (2.0)\cdot10^{34}$
Repetition rate (Hz)	50			
Loaded accel. Gradient (MV/m)	80		100	
Main linac RF frequency (GHz)	12			
Bunch charge (10^9)	6.8		3.72	
Bunch separation (ns)	0.5			
Beam pulse duration (ns)	177		156	
Beam power/beam (MW)	4.9		14	
H/V norm. Emitt ($10^{-6}/10^{-9}$) (m.rad)	7.5 / 40	4.8 / 25	7.5 / 40	0.66 / 20
H/V IP beam size (nm)	248 / 5.7	202 / 2.3	101 / 3.3	40 / 1
BDS length (km)	1.87		2.75	
Total site length (km)	13.0		48.3	
Wall plug to beam transfert eff	7.5 %		6.8 %	
Total power consumption (MW)	241		568	


Drive beam - 100 A, 240 ns
from 2.4 GeV to 240 MeV
QUAD
QUAD
POWER EXTRACTION
STRUCTURE (PETS)
ACCELERATING
STRUCTURES
12 GHz with 2 x 68 MW
BPM
Main beam – 1 A, 156 ns
from 9 GeV to 1.5 TeV

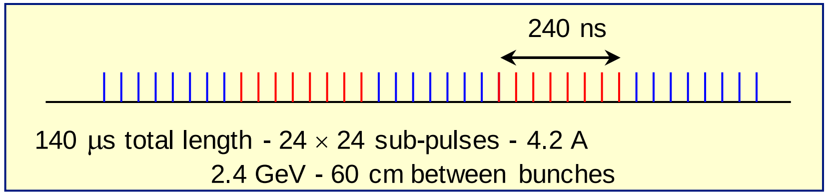
The CLIC RF power source can be described as a “black box”, combining *very long beam pulses*, and transforming them in *many short pulses*, with *higher intensity* and with *higher frequency*



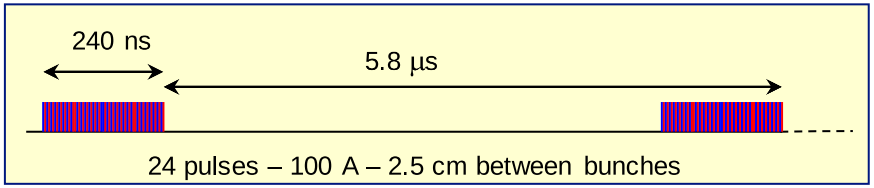
The Drive Beam generation



Drive beam time structure - initial

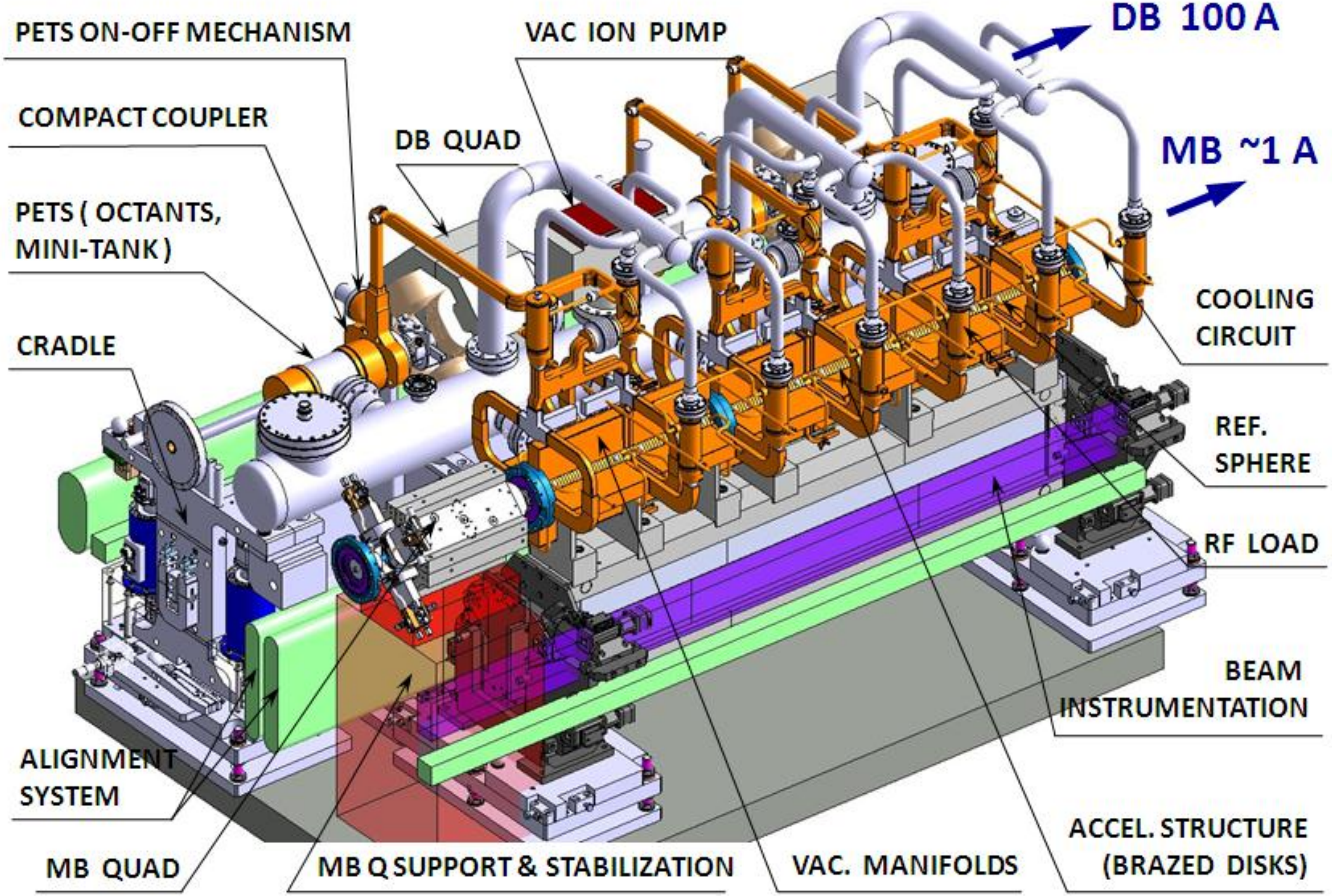


Drive beam time structure - final



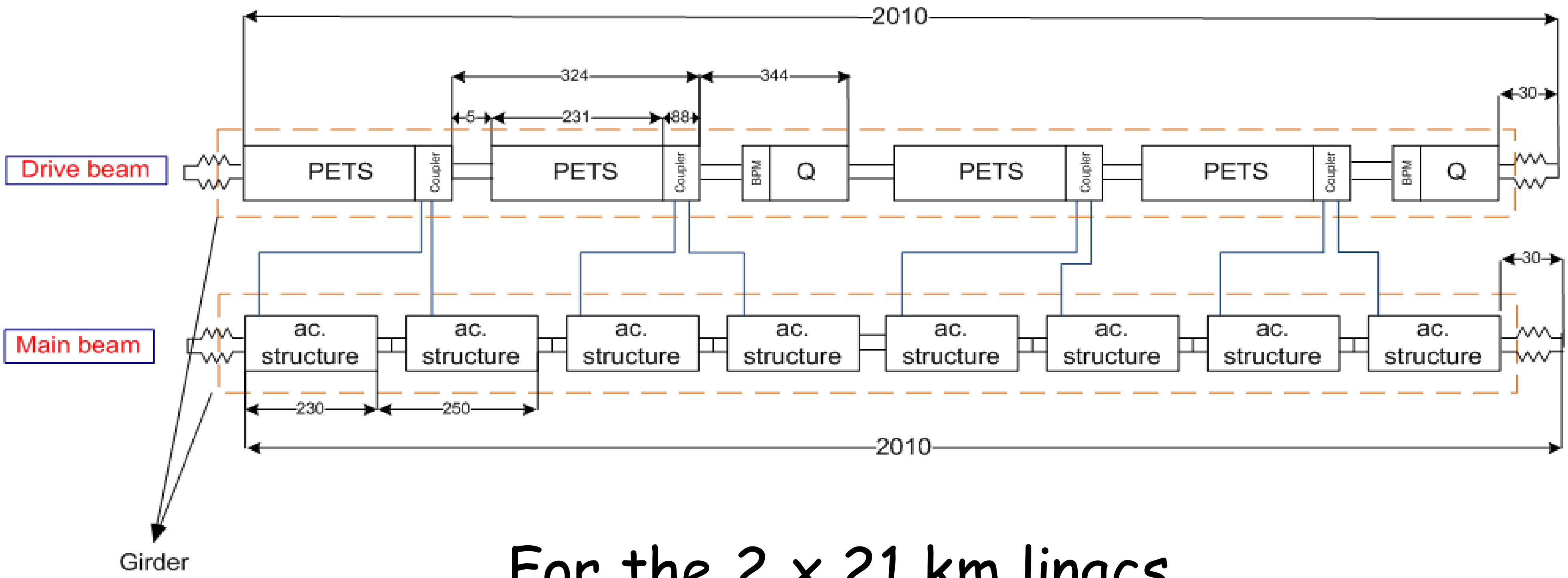
CLIC Two-Beam Module

A. Samoshkin



CLIC Two-Beam Module

G. Riddone



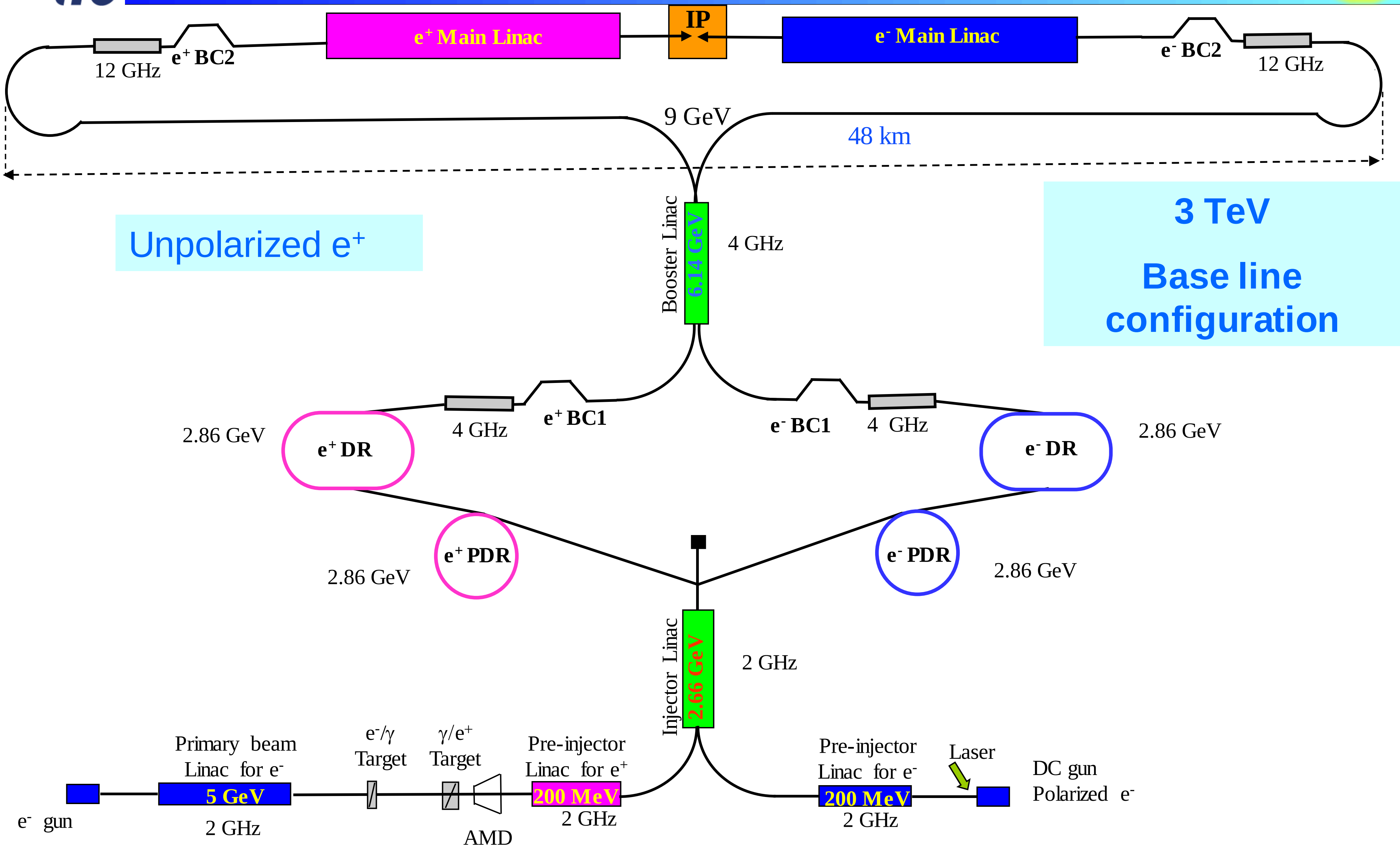
For the 2 x 21 km linacs

20 924 CLIC modules of 2.010 m each

71 406 Power Extraction and Transfer Structures (PETS) for the Drive Beams

142 812 CLIC Accelerating Structures (CAS) for the Main Beams

CLIC Main Beam Injector Complex



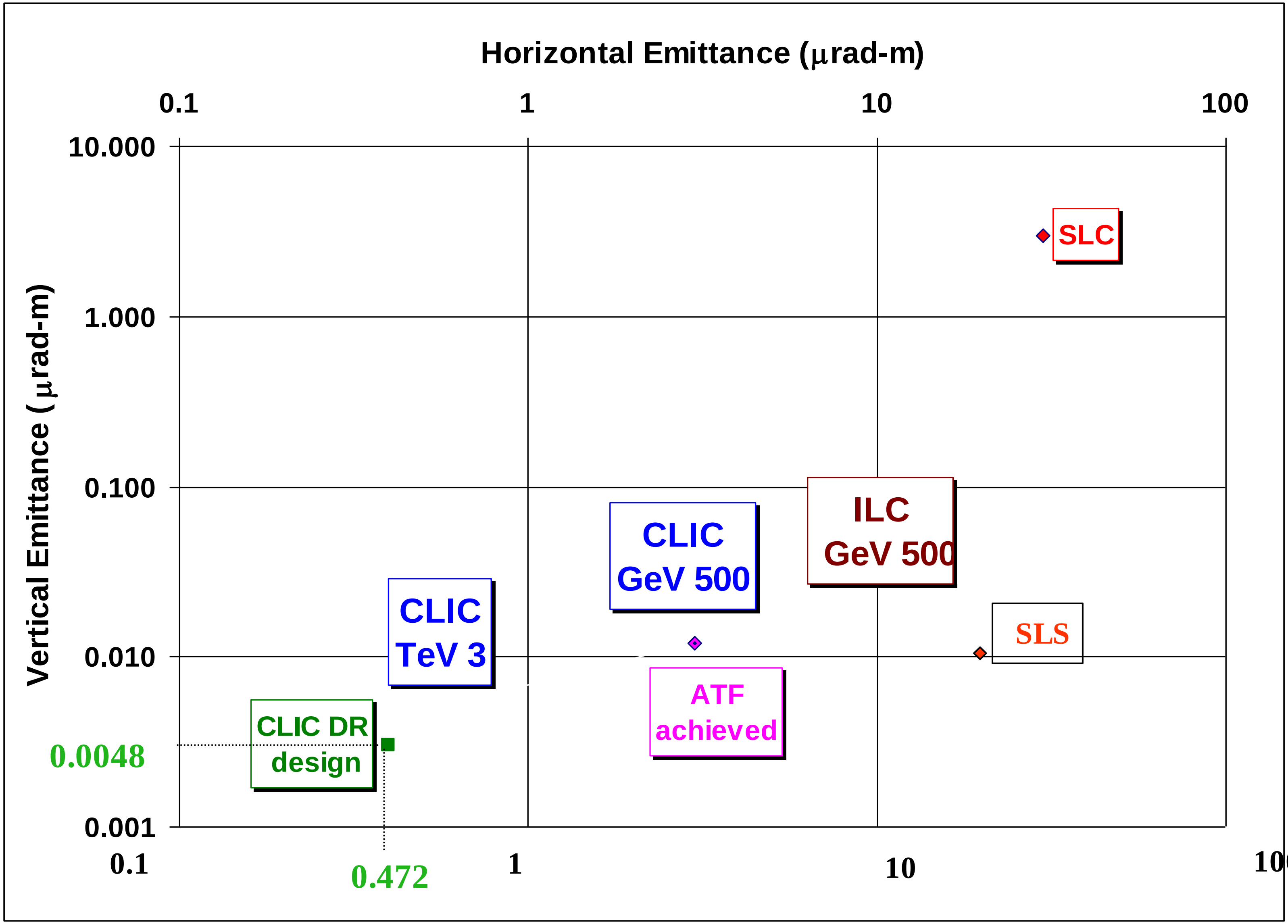
Flux of e^+

	SLC (California)	CLIC (3 TeV)	CLIC (0.5 TeV)	ILC (RDR)	LHeC (CERN)
Energy	1.19 GeV	2.86 GeV	2.86 GeV	5 GeV	100 GeV
e^+/ bunch (at IP)	40×10^9	3.7×10^9	7.4×10^9	20×10^9	15×10^9
e^+/ bunch (before PDR or DR injection)	50×10^9	7×10^9	14×10^9	30×10^9	15×10^9
Bunches / macropulse	1	312	354	2625	20833
Macropulse Repet. Rate (Hz)	120	50	50	5	10
e^+ / second $\times 10^{14}$	**0.06**	**1.1**	**2.5**	**3.9**	**31**

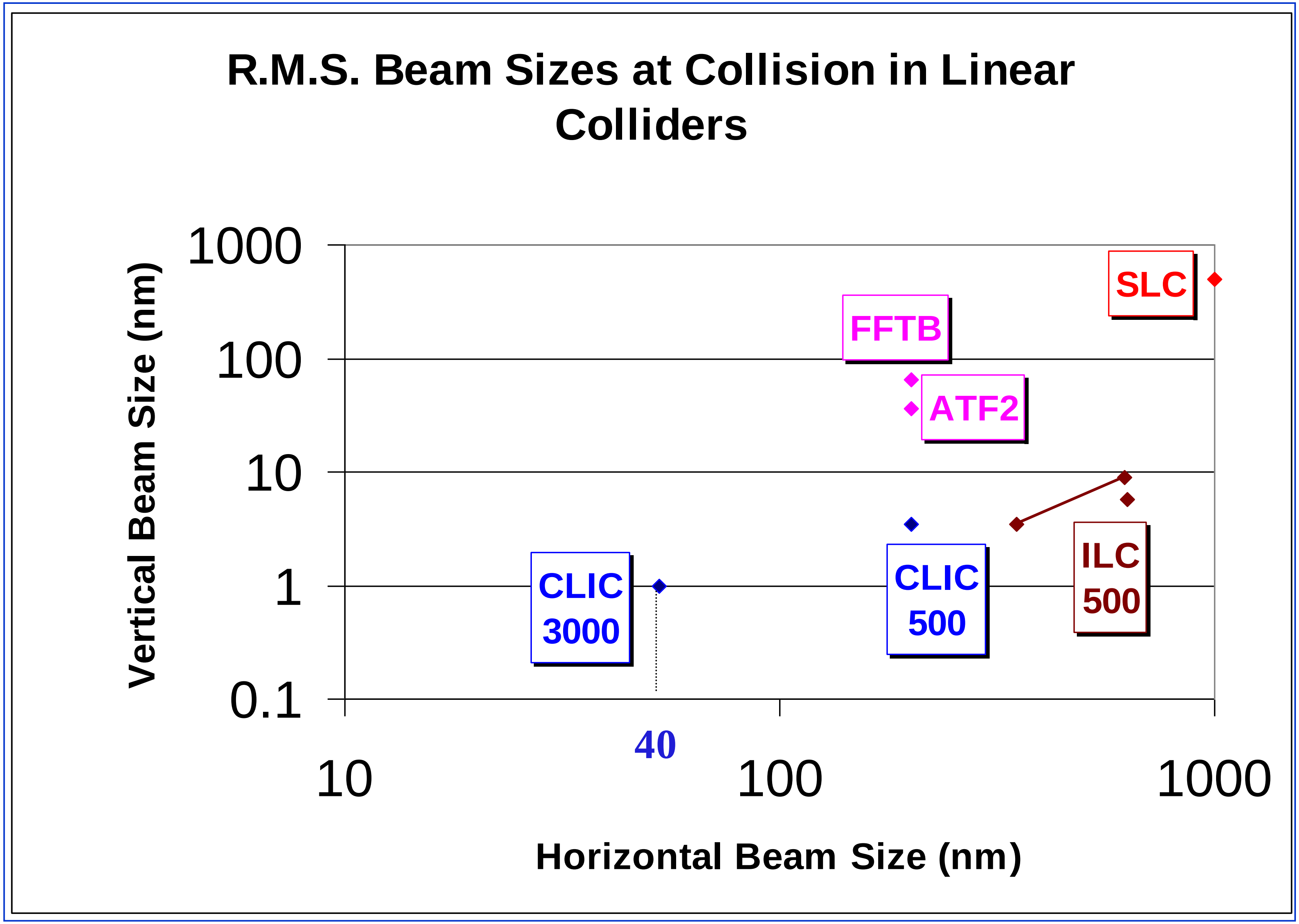
x 42

The challenge of the small beam emittances

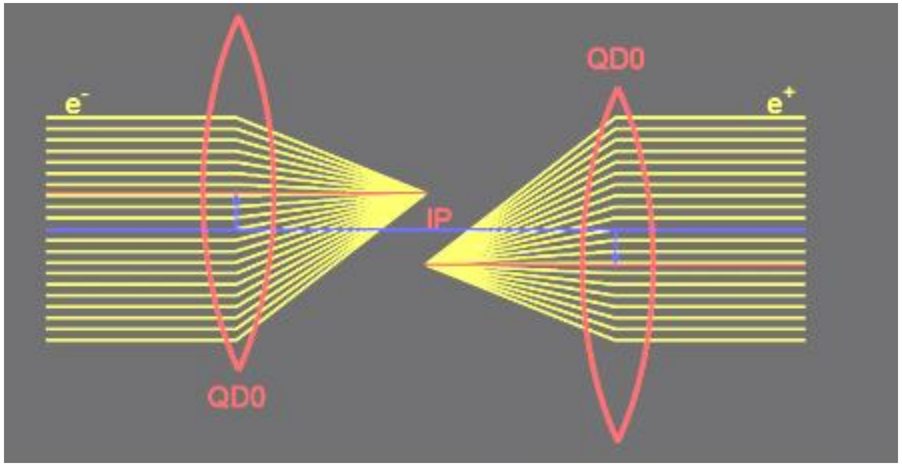
Normalized rms emittances at the Damping Ring extraction



Beam sizes at collisions



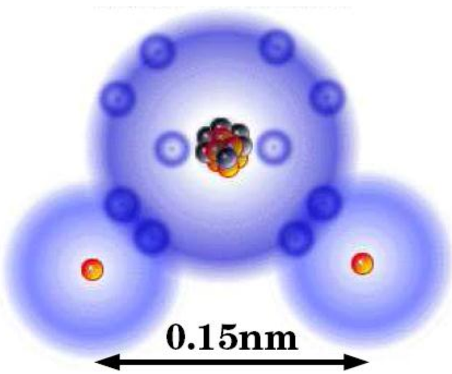
Vertical spot size at IP is 1 nm



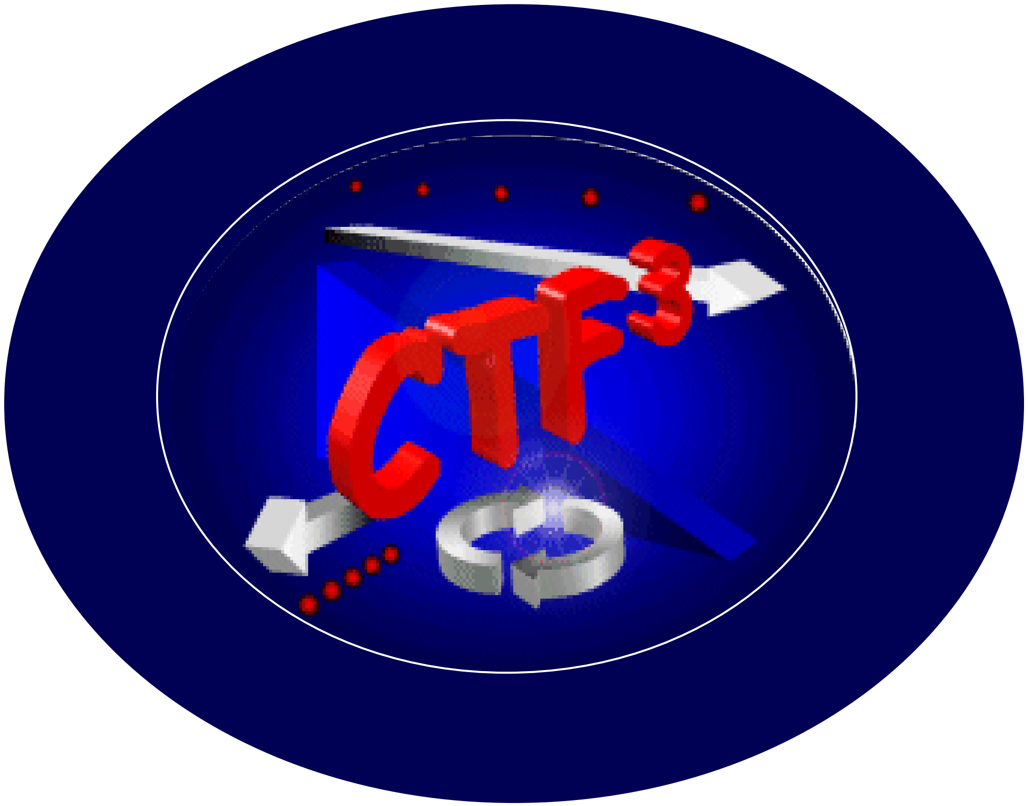
Stability requirements (> 4 Hz) for a 2% loss in luminosity

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

H_2O molecule



The CLIC Test Facilities



A very short overview of the CTF stages

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

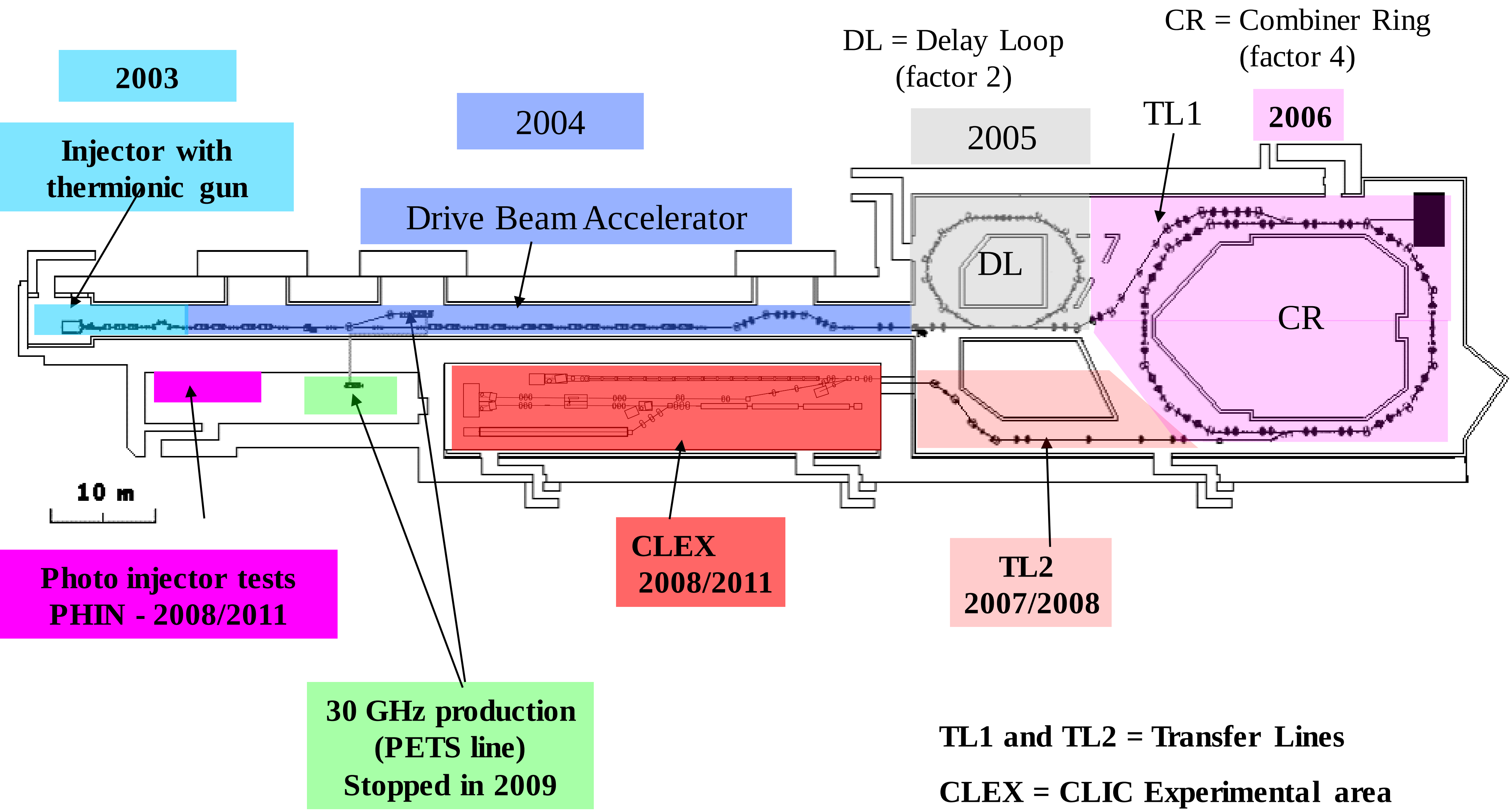
2001-2003: CTF 3 = CLIC Test Facility 3 (Preliminary phase)

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

2003-2012: 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

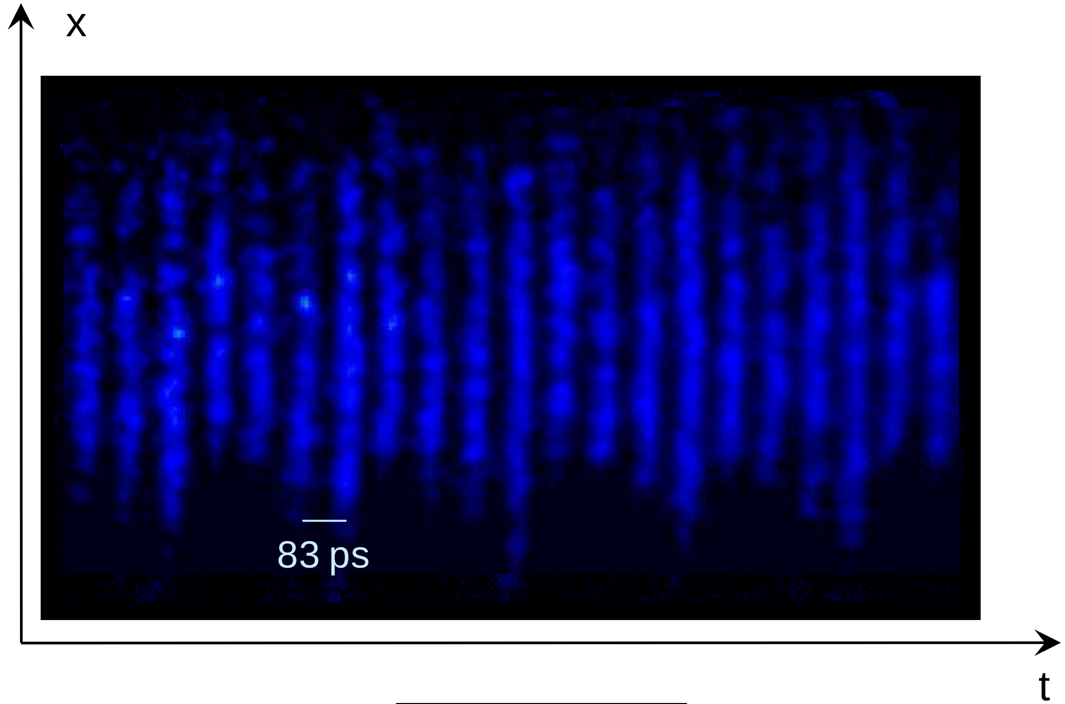
CTF3 evolution



TL1 and TL2 = Transfer Lines

CLEX = CLIC Experimental area

Recorded during the CTF 3 Preliminary phase



4th turn

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

CTF2 hall

including Photoinjector PHIN

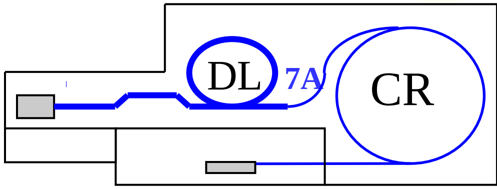
CLEX hall

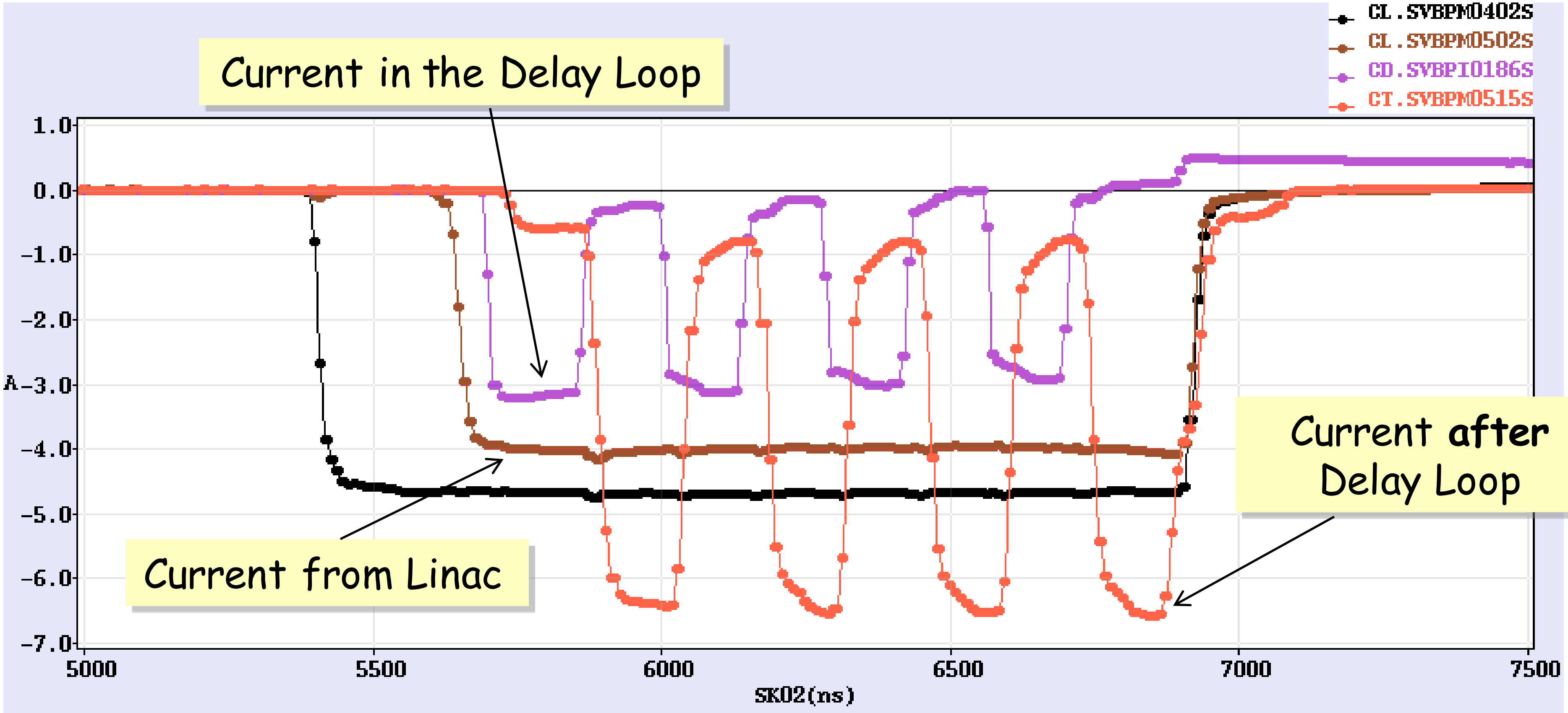
CTF3 Injector Linac

Delay Loop Injection area

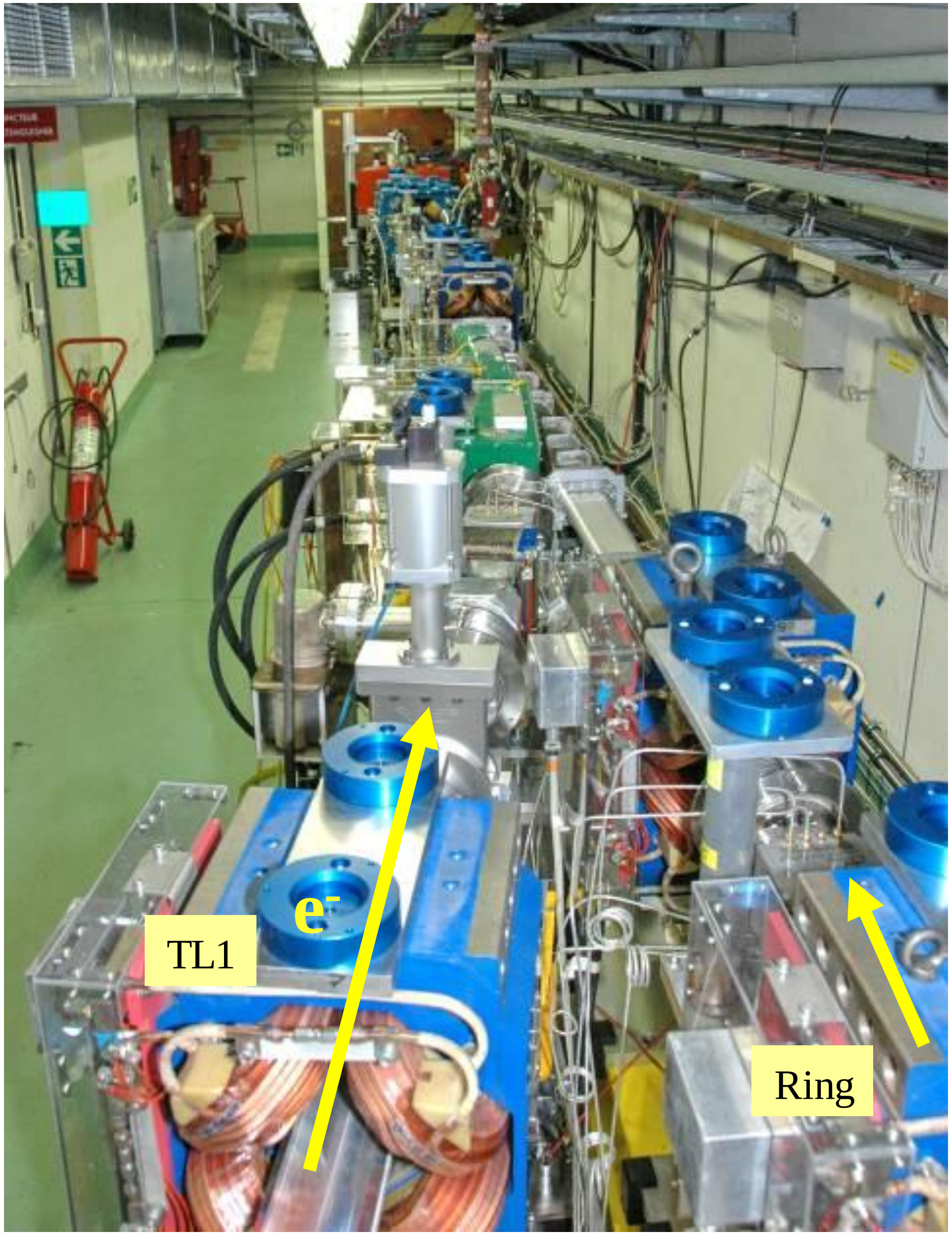
Beam recombination in the Delay Loop

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

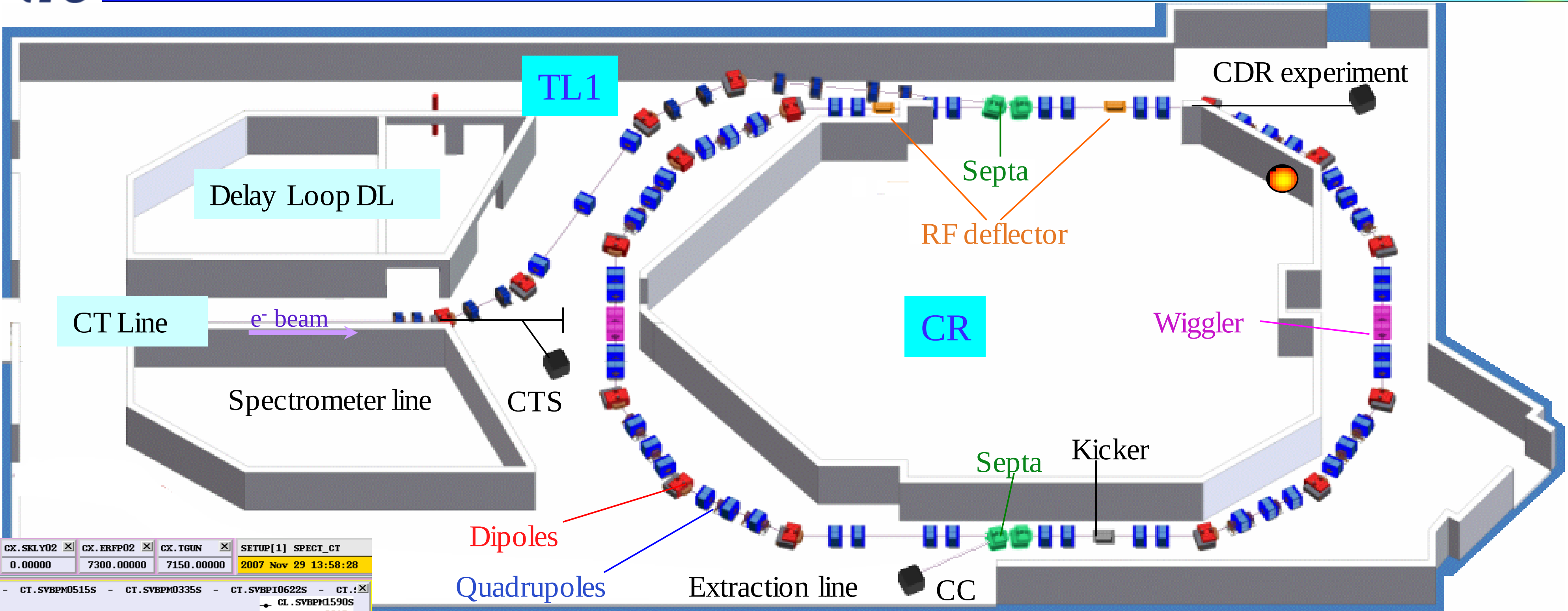


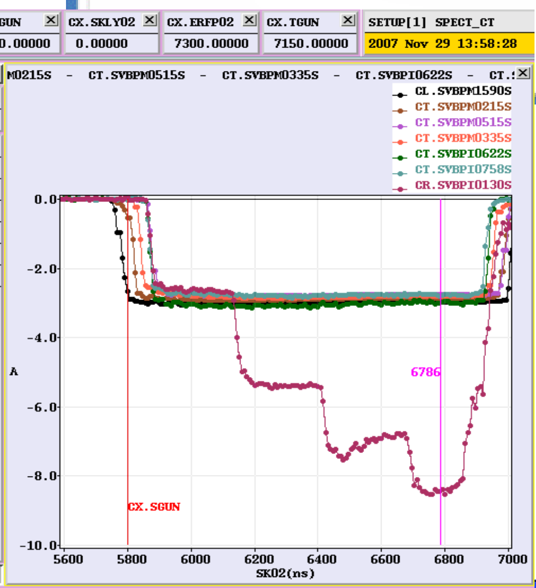


Injection region in the Combiner Ring



Combiner Ring

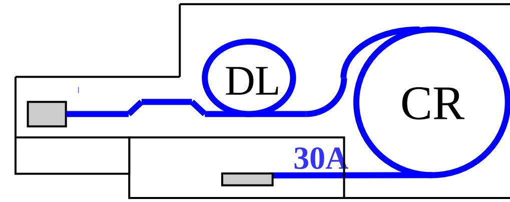


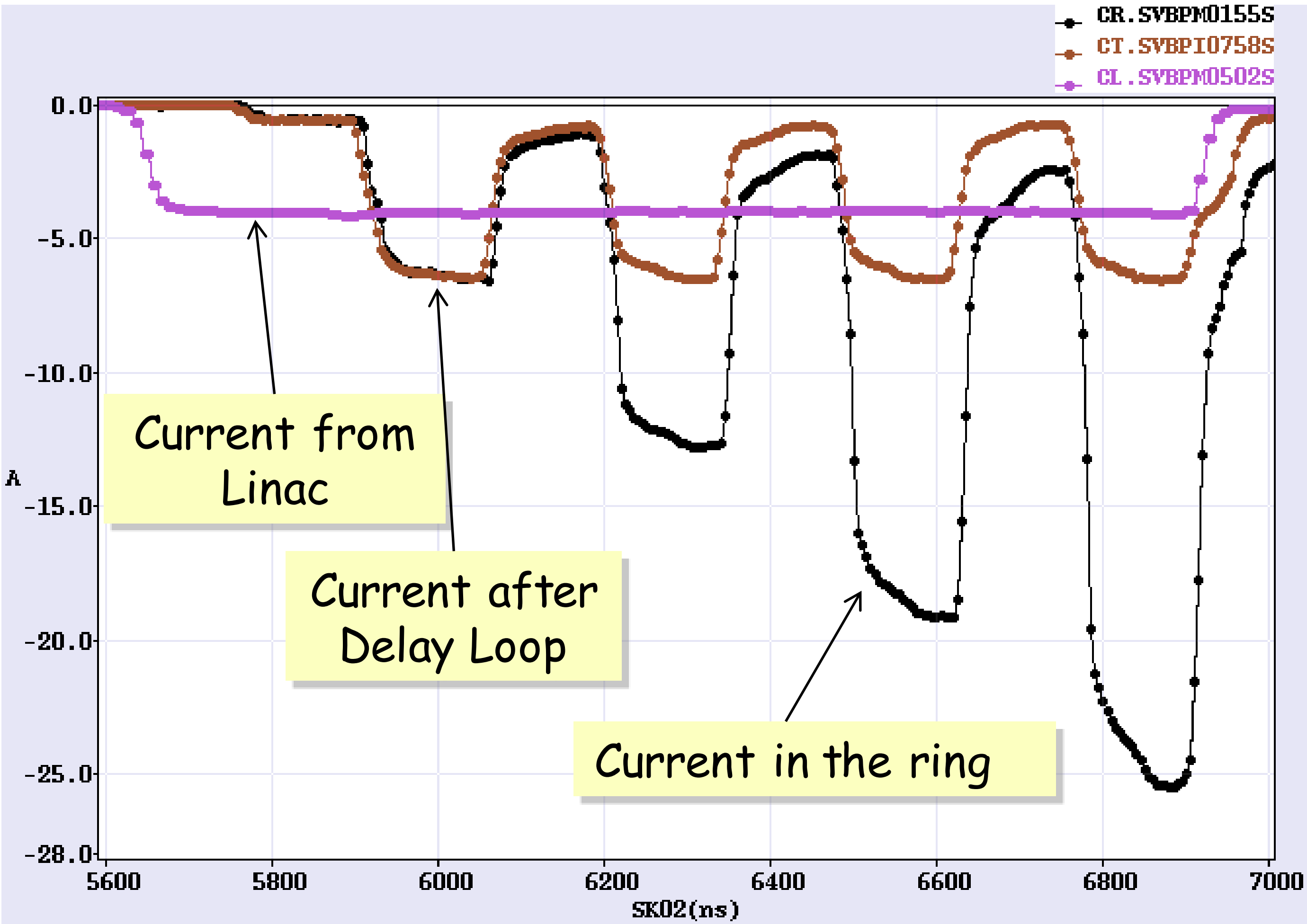


First combination with a factor 4
(November `07)

Beam recombination in both rings

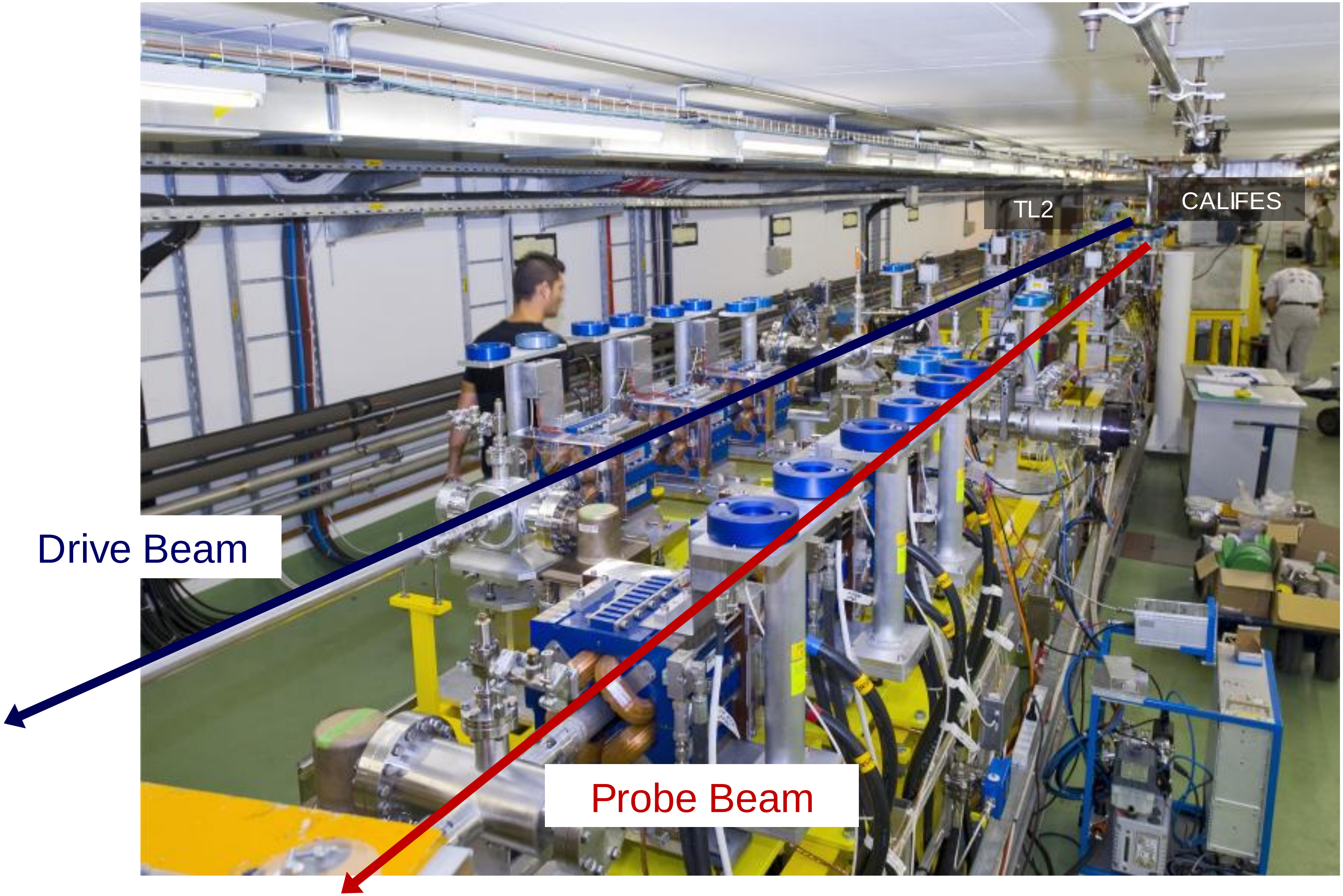
- factor 8 combination achieved with 26 A, 140 ns (Delay Loop + Combiner Ring))





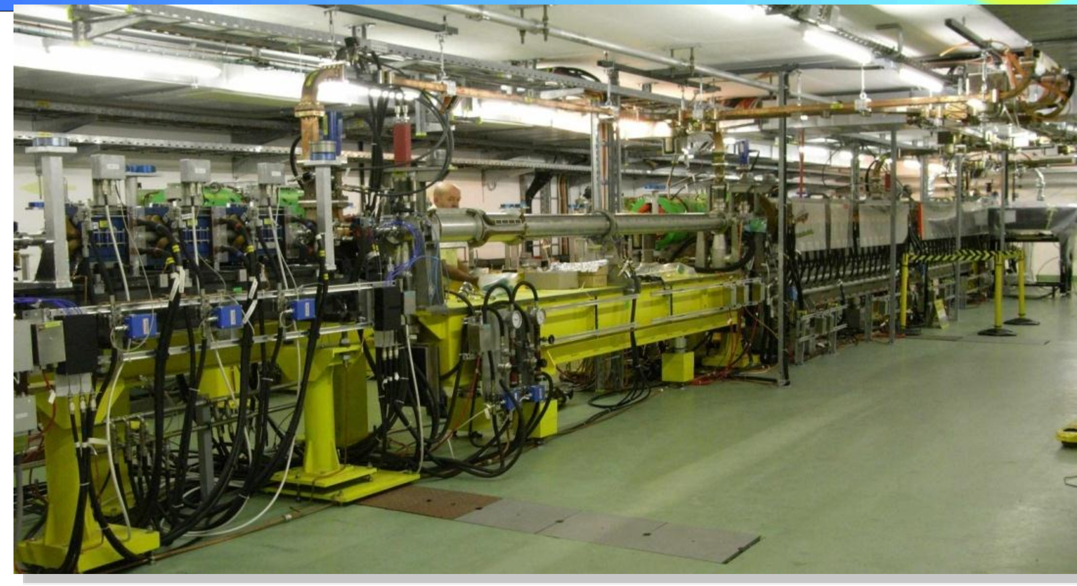
Transfer line TL2 from Combiner Ring to CLEX

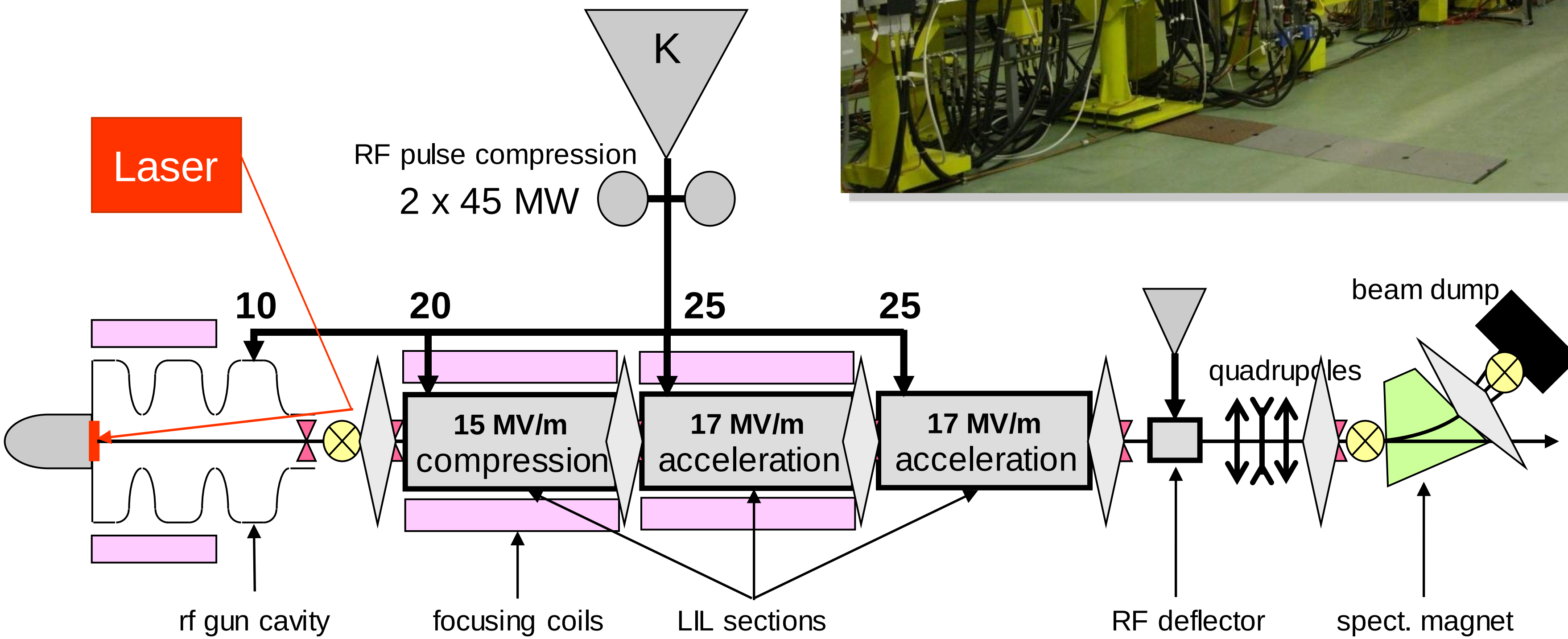
Two Beams in CLEX



Probe Beam CALIFES

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





C A L I F E S = Concept d'Accélérateur Linéaire pour Faisceau d'Electrons Sonde

IRFU (DAPNIA), CEA, Saclay, France

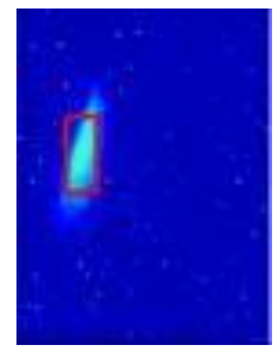
Problem with RF deflecting cavity CALIFES ?

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
σ_y = 0.24 mm



Cavity ON
σ_y = 1.47 mm

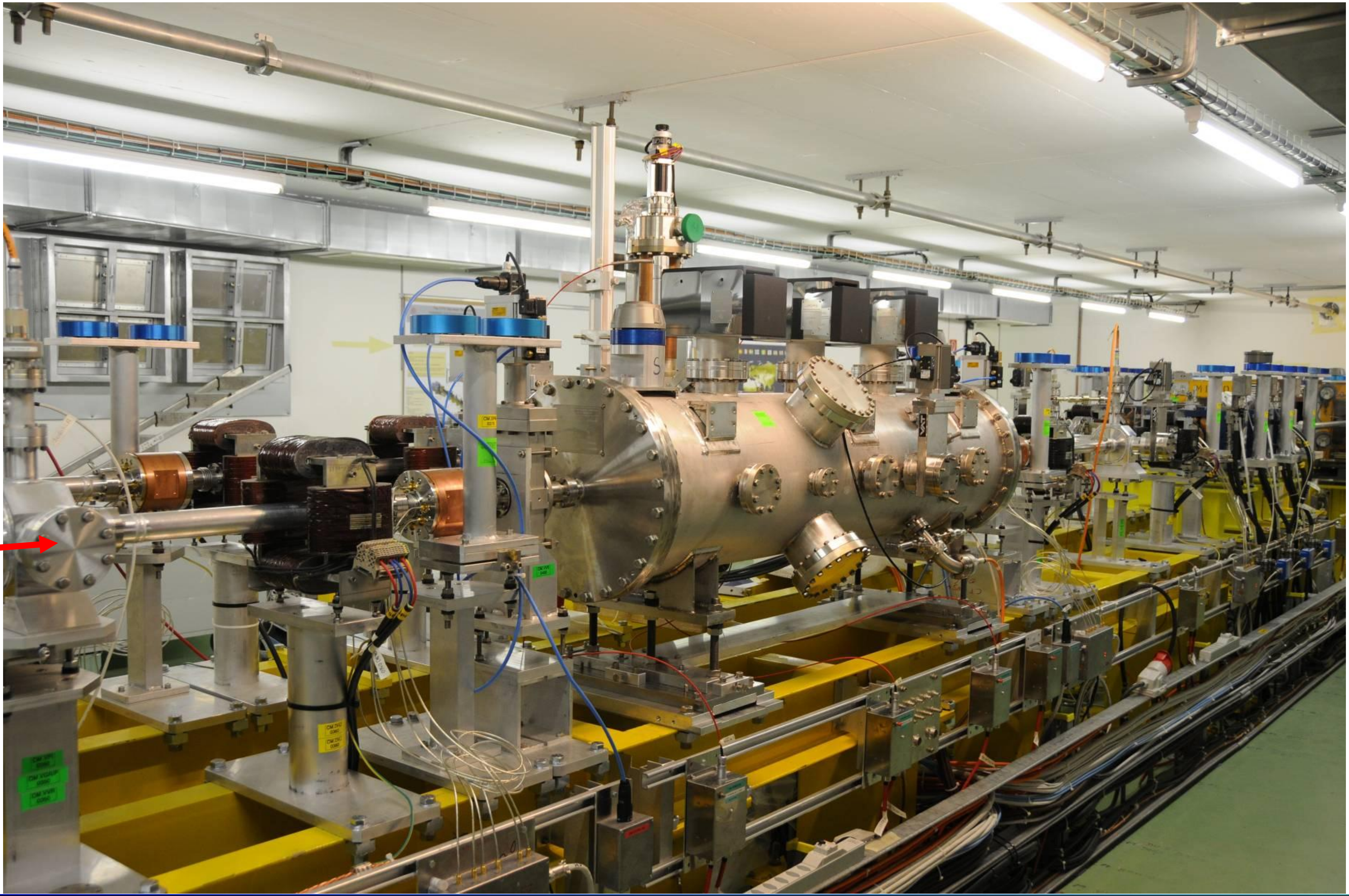
$\Rightarrow$ Electron bunch length σ_t = 1.42 ps

with a laser pulse σ_t = 7 ps

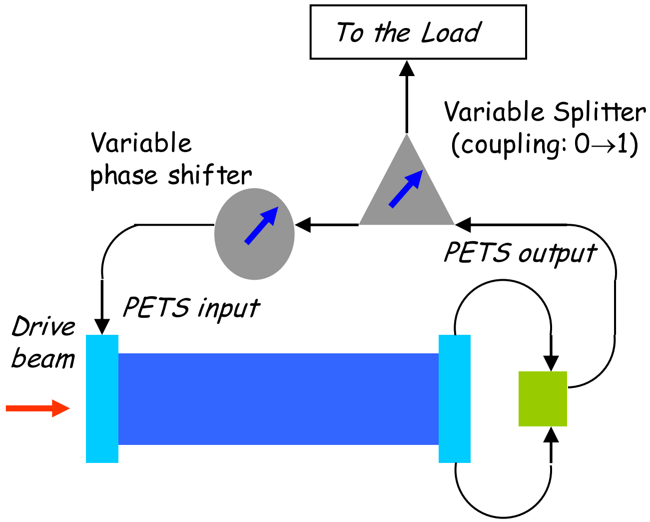
PETS tank on Drive Beam line into CLEX

PETS = Power Extraction and Transfer Structure

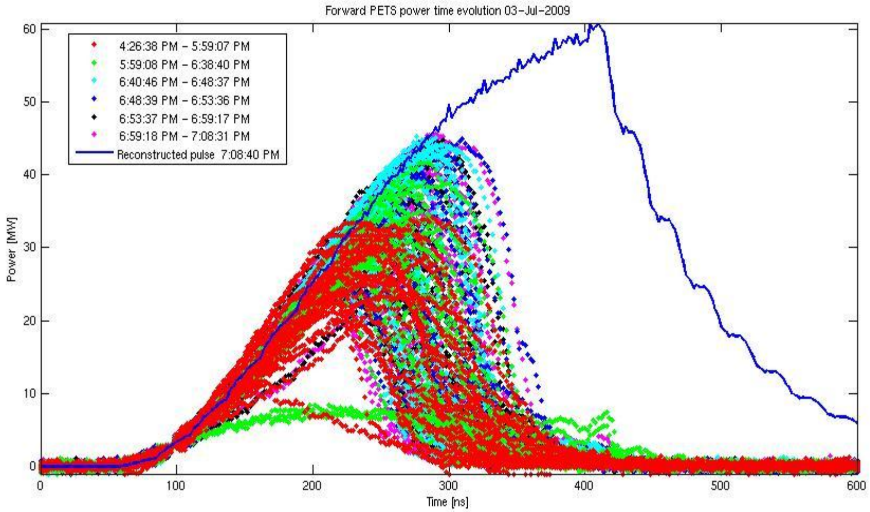
e$^-$



RF power produced by PETS



- 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:

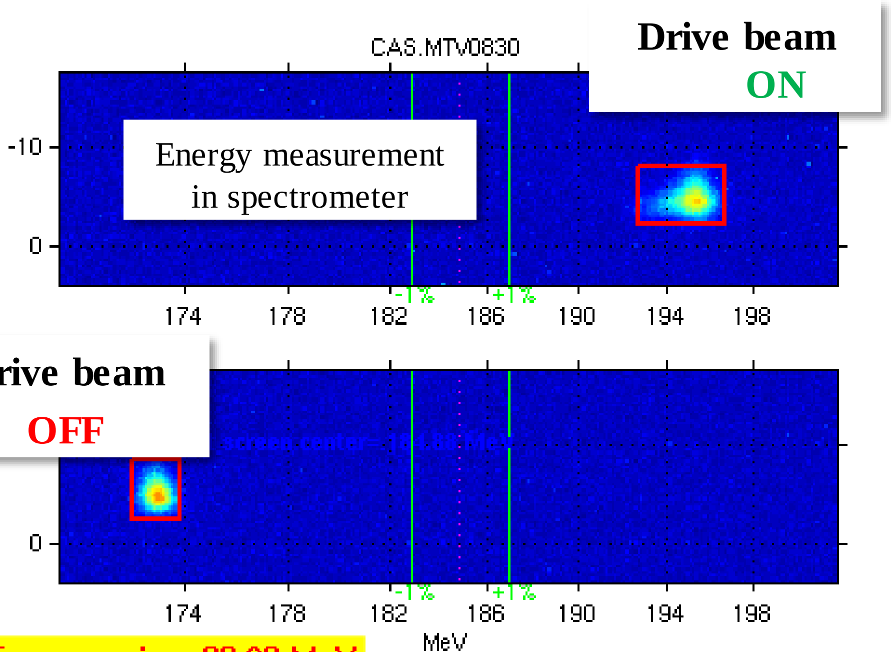
  * no flat top
  * still RF breakdowns

Two-Beam Acceleration demonstration

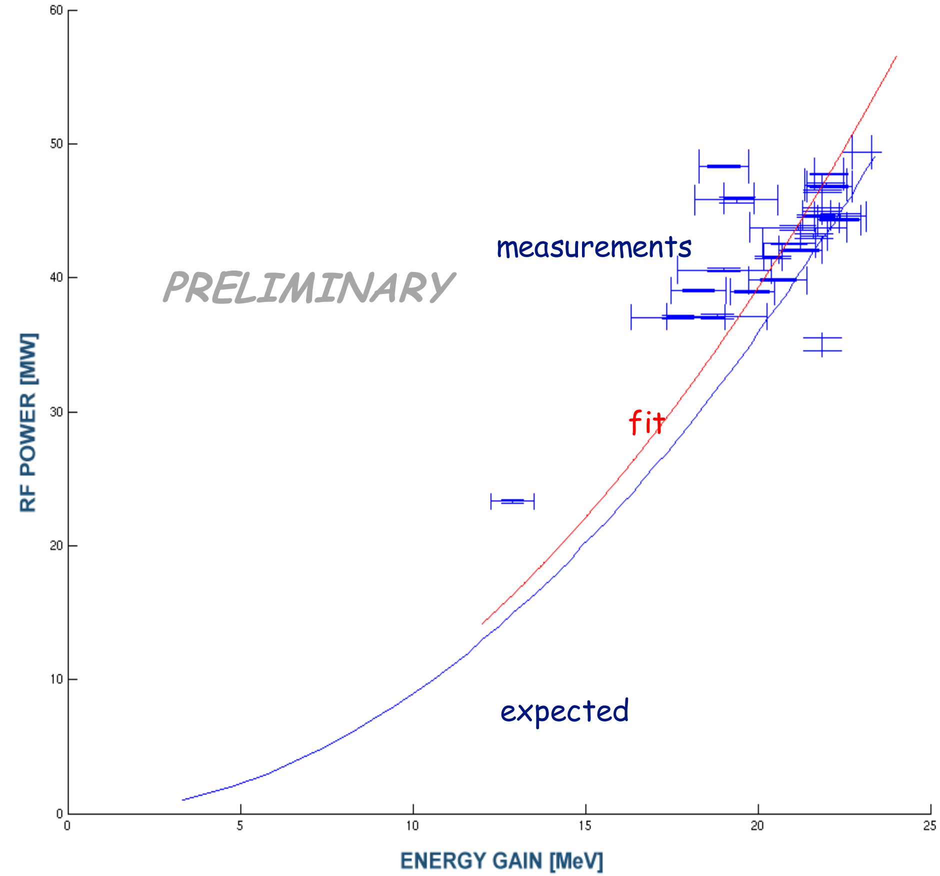
Maximum probe beam acceleration of 23 MeV measured (with structure heated to 60°C)

=> Corresponding to a **gradient** of **106 MV/m**

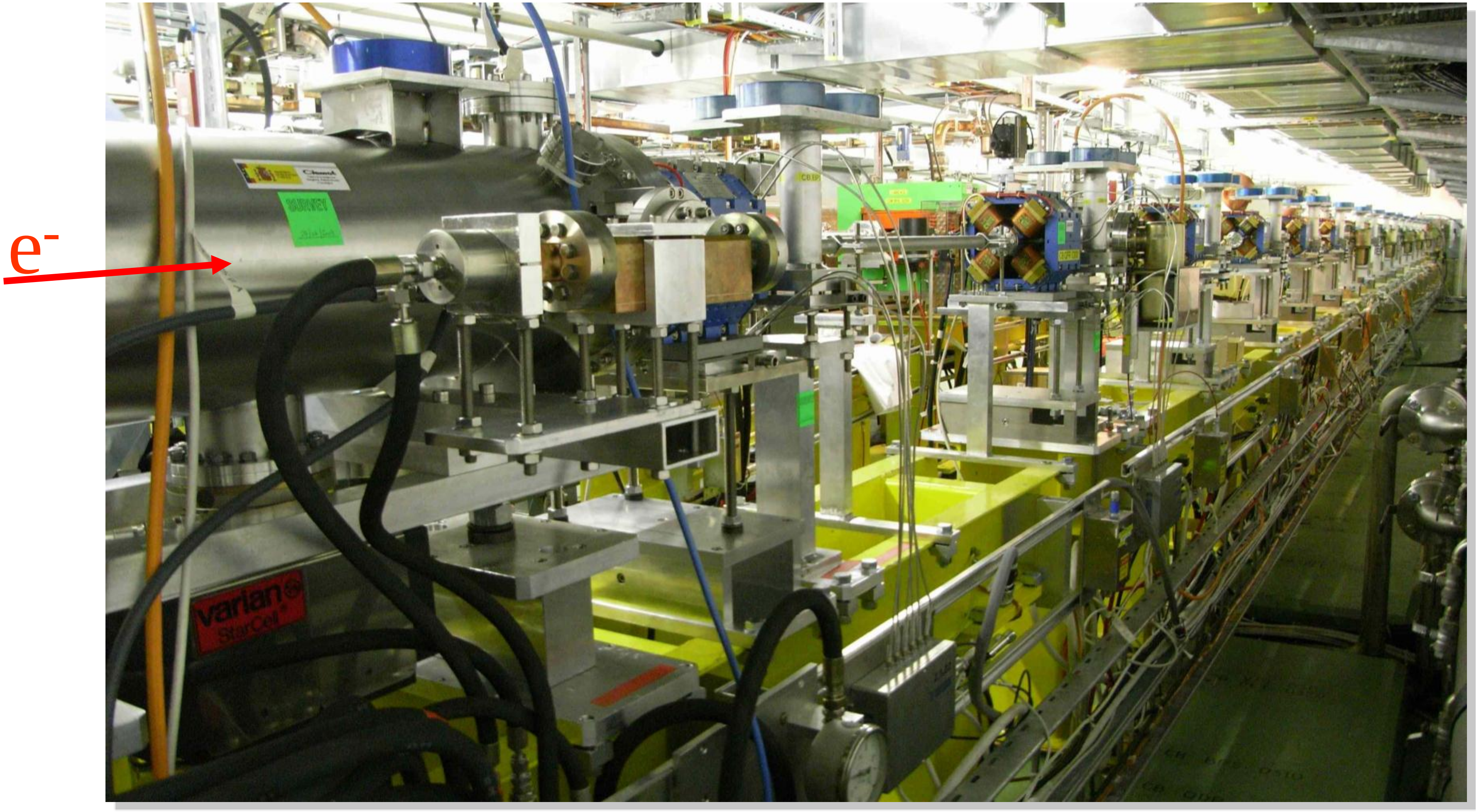
TD24 accelerating structure



Energy gain = 23.08 MeV



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

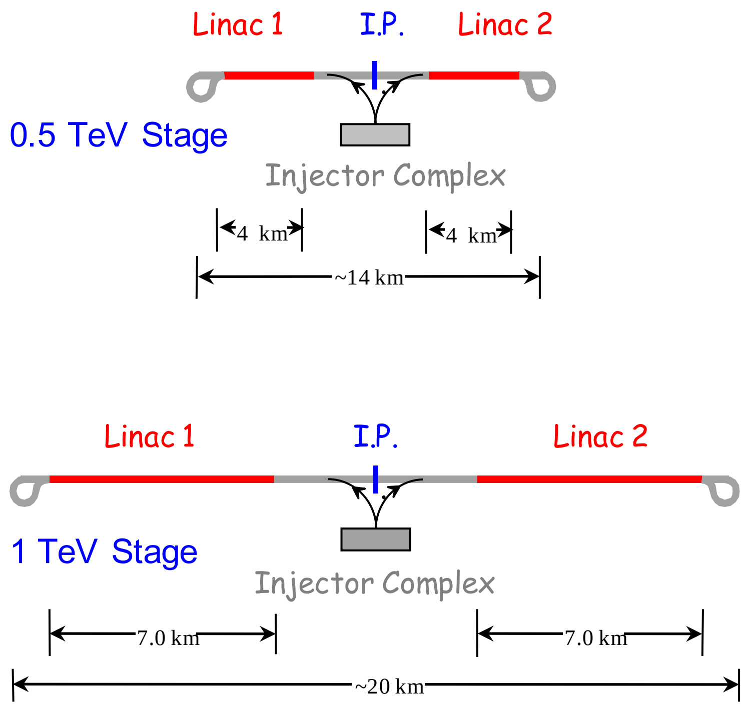
		CTF3	CLIC
Energy	GeV	0.15	2.4
Current	A	32	100
Normalized (geom) emittance	mm mrad	100 (0.3)	100 (0.02)
Pulse length	ns	140	240
train length in linac	μs	1.2	140
RF Frequency	GHz	3	1
Compression factor		2 x 4	2 x 3 x 4

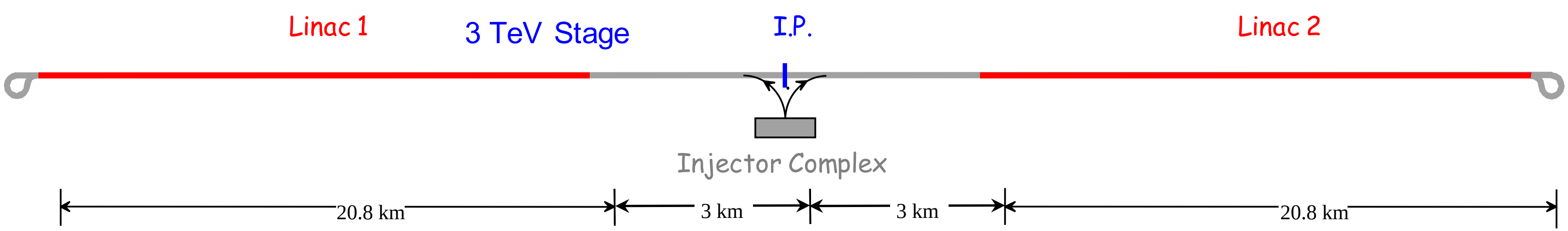
CLIC energy staging

CLIC two-beam scheme compatible with energy staging to provide the optimal machine for a large energy range

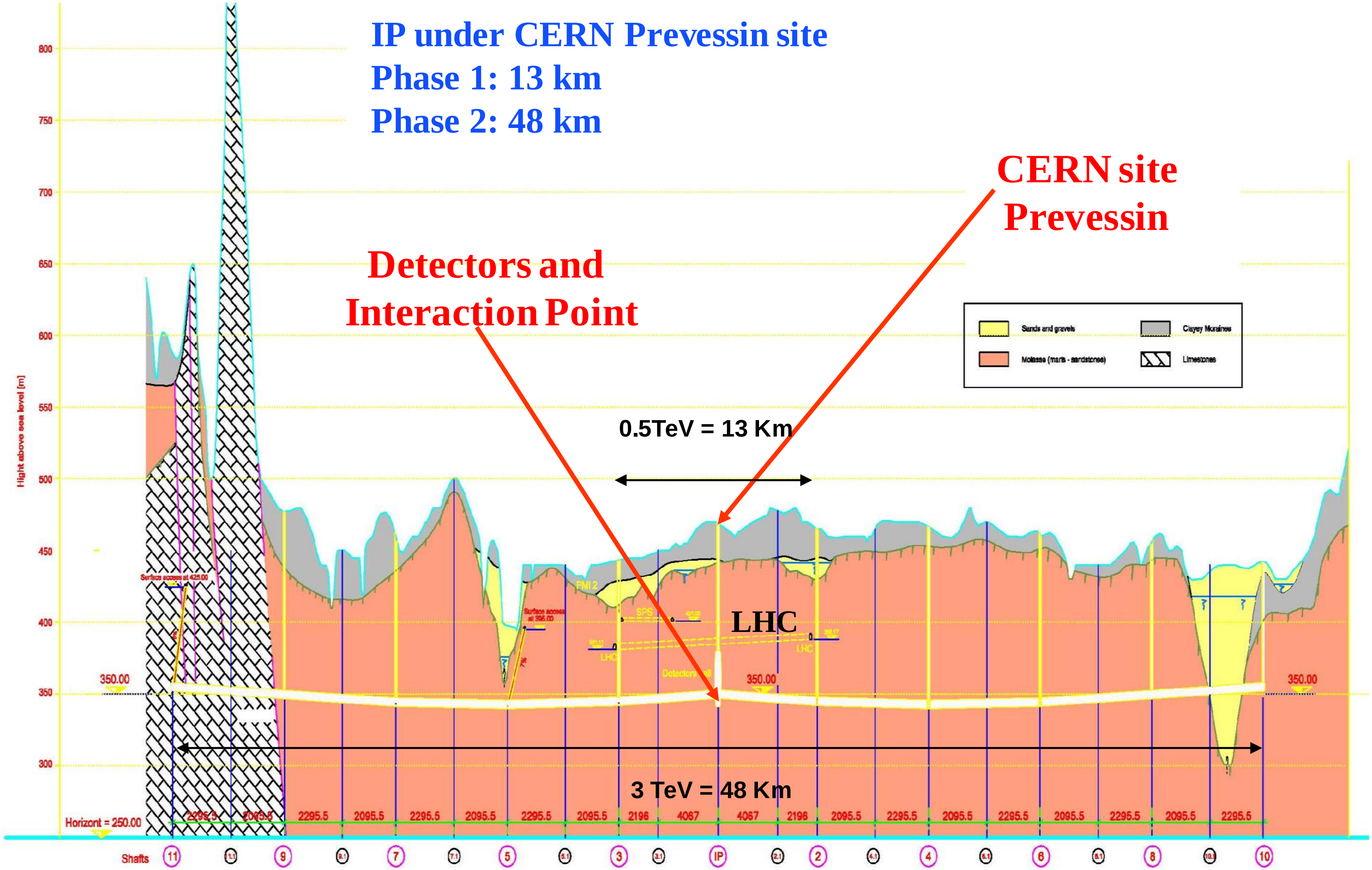
Lower energy machine can run most of the time during the construction of the next stage. Physics results will determine the energies of the stages.

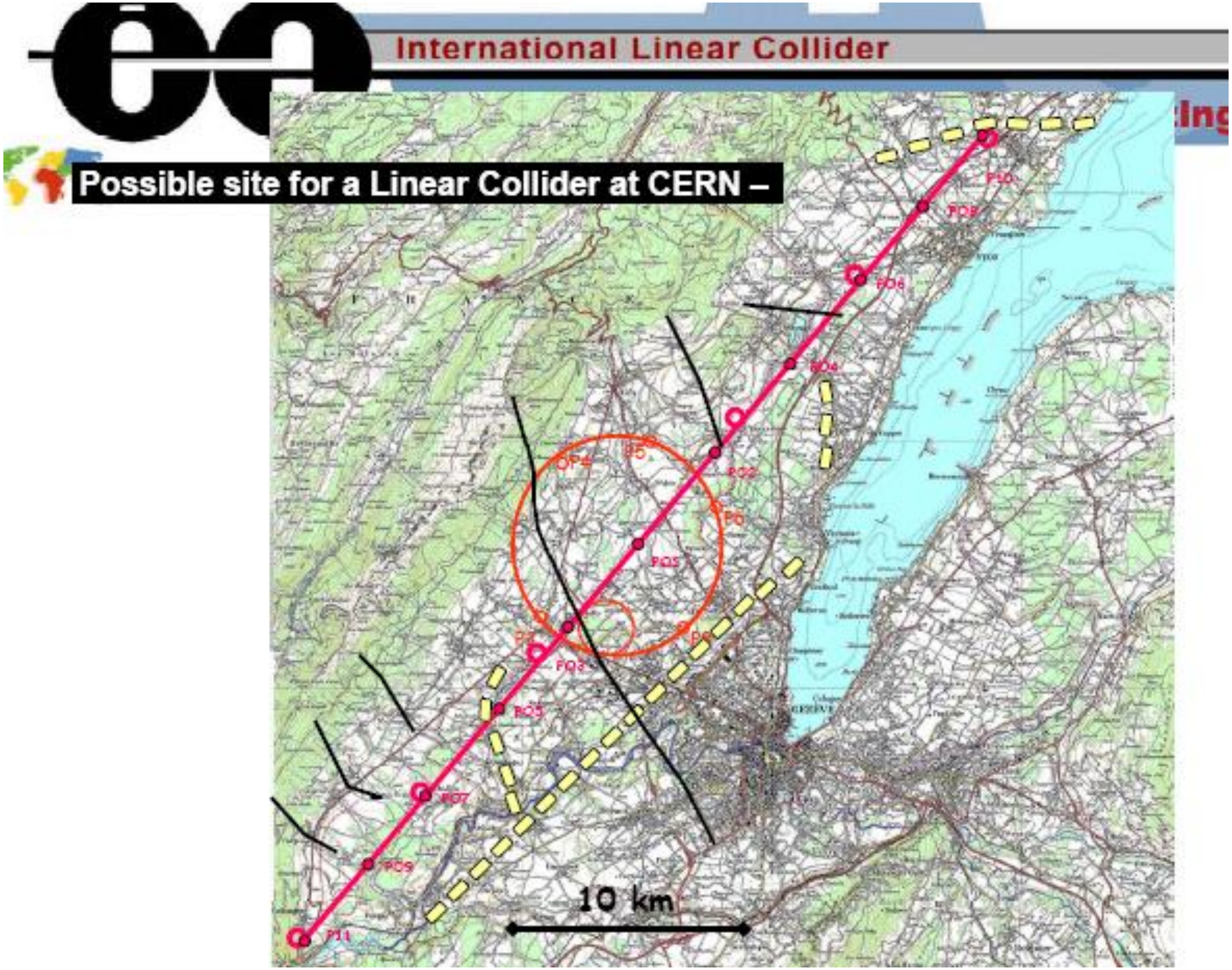
Optimization need to take into many account many others parameters: performance and luminosities at various energies, costs, construction and commissioning times, manufacturing/re-use/move of components, etc



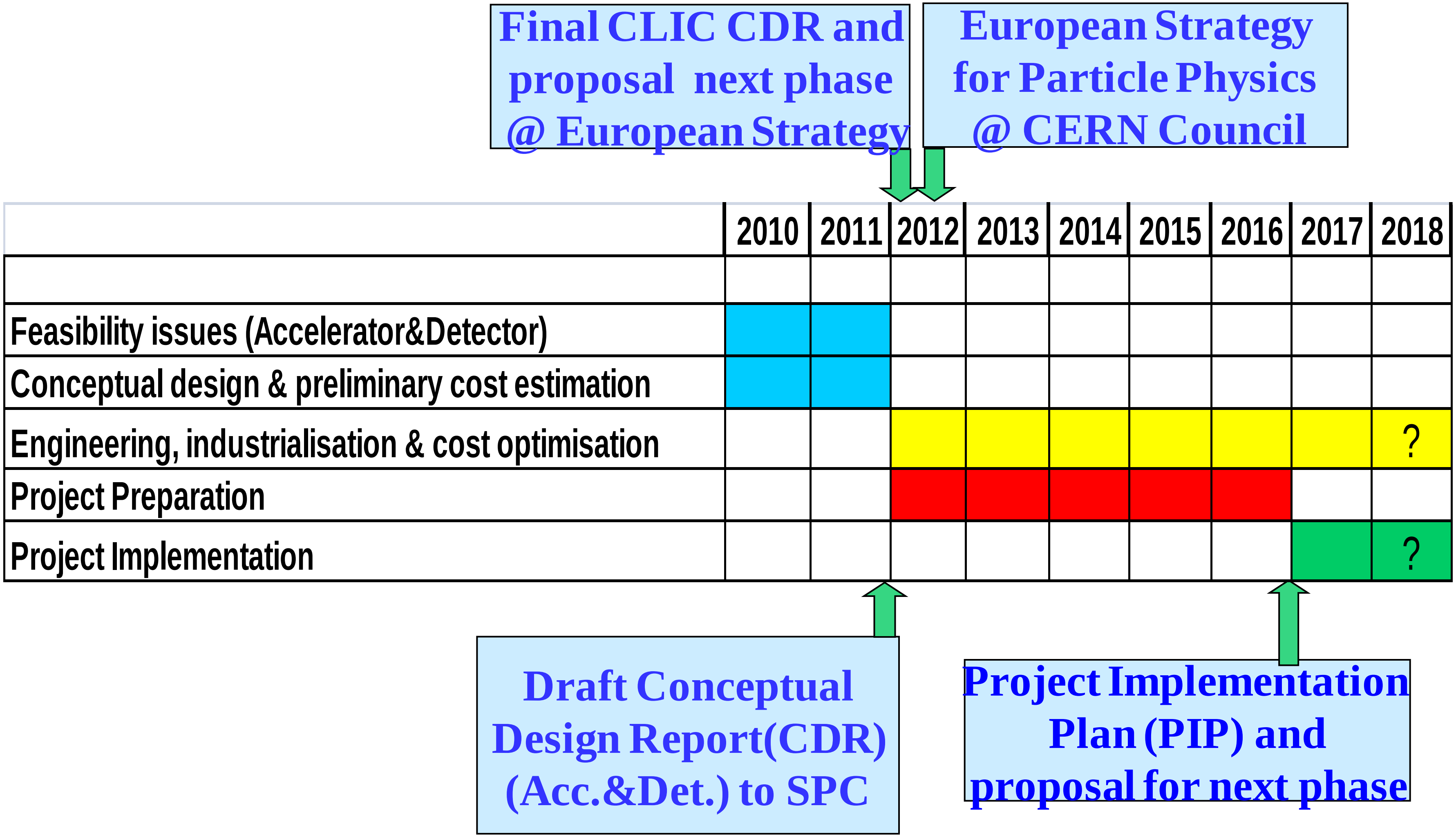


Longitudinal section on CERN site




International Linear Collider
Possible site for a Linear Collider at CERN –
10 km

Tentative CLIC schedule (February 2011)



Final remark at CLIC09 workshop

B. Barish / GDE

- 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.

The next years

R. Heuer / CERN DG

Important steps in the coming years

- ❑ CDR for CLIC 2011
- ❑ TDR for ILC 2012

• ICFA Seminar at CERN 3-6 October 2011

use this occasion to

- layout exciting future prospects in particle physics
- synchronize regional strategies/roadmaps

• Update of European strategy for particle physics start: EPS 2011, finalize Sept. 2012

• IEEE 2012 special event to promote LC

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) without cost estimate will be published by 2012

A Technical Design Report (TDR) will follow

Your participation is warmly welcome to the CLIC and ILC studies

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