Update on ILC Accelerator Design and Linear Colliders R&D

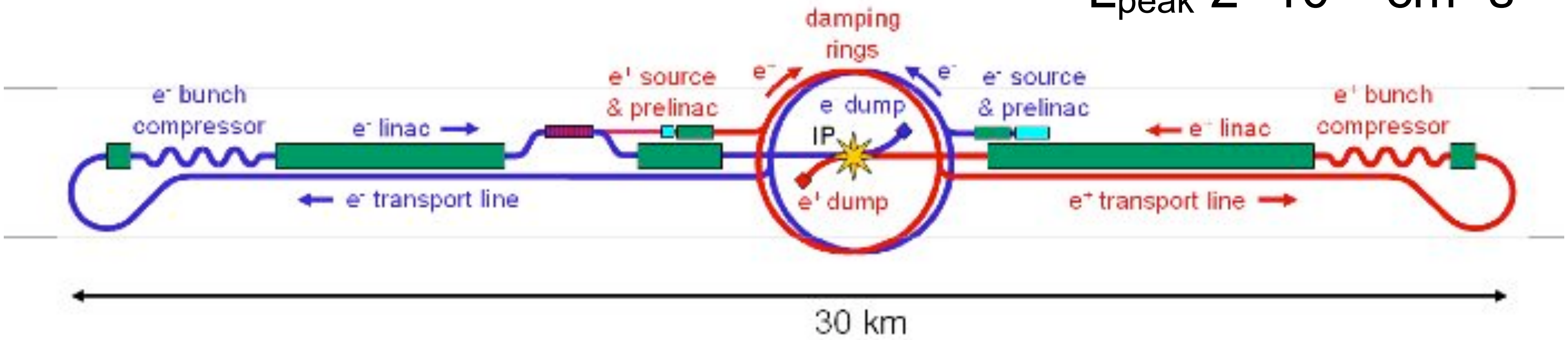
S. Guiducci

INFN-LNF

LC09, Perugia 23/9/2009

ILC Layout

E_{CM} 500 GeV
L_{peak} 2×10^{34} $cm^{-2}s^{-1}$



- Polarized e^- source based on a photocathode DC gun
- Undulator-based e^+ source, driven by 150 GeV electrons
- 5 GeV e^- and e^+ damping rings (DR)
- Two 11 km long main linacs, with 1.3 GHz SCRF cavities
- A single interaction region shared by two detectors, 14 mrad crossing angle

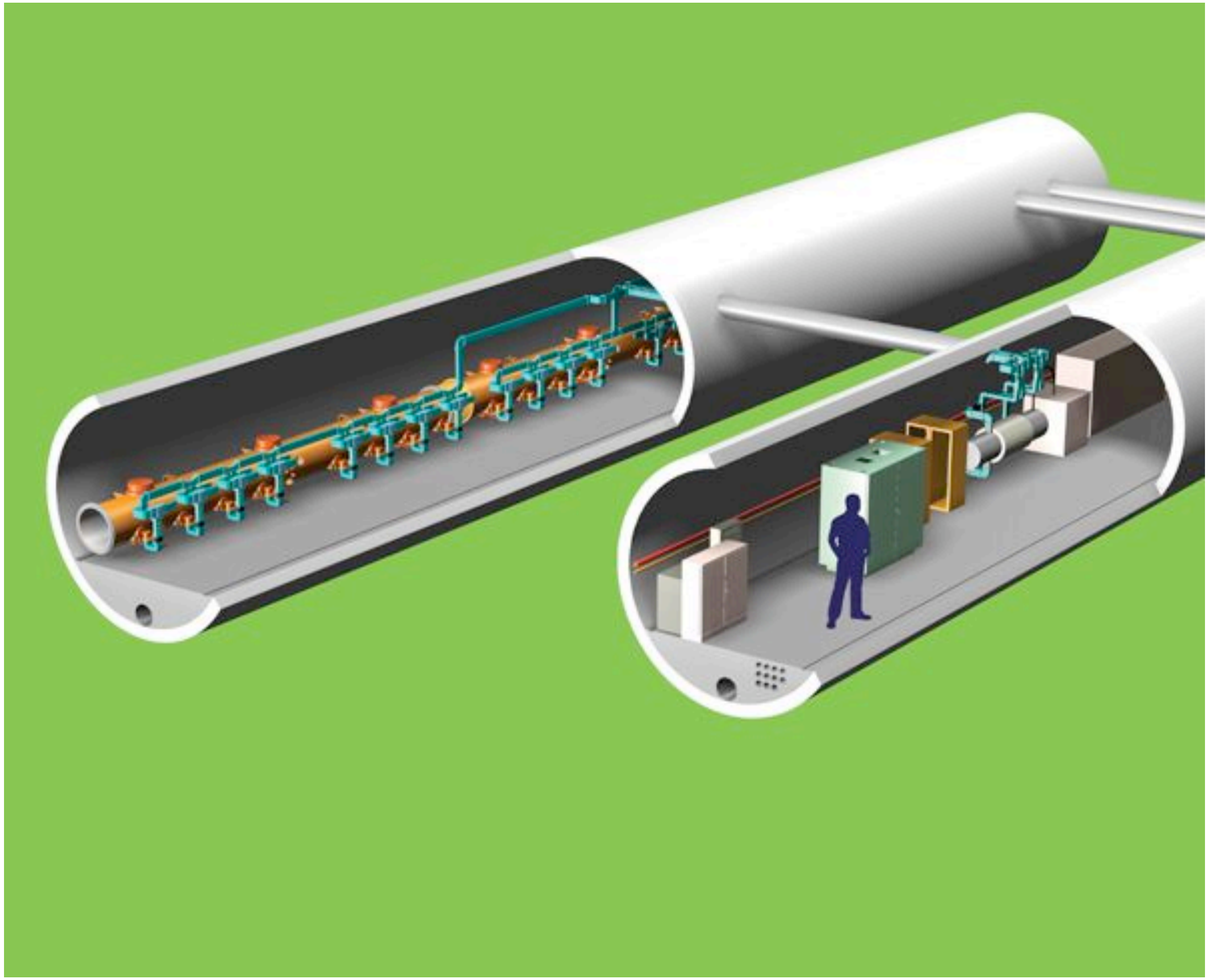
Basic design parameters

Center-of-mass energy	GeV	500
Peak luminosity	cm-2s-1	2×10^{34}
Beam current	mA	9.0
Pulse rate	Hz	5.0
Pulse length (beam)	ms	~1
Number of bunches per pulse		2600
Charge per bunch	nC	2
Accelerating gradient	MV/m	31.5
RF pulse length	ms	1.6
Beam power (per beam)	MW	10.8
Typical beam size at IP1 ($h\times v$)	nm	640×5.7
Total AC Power consumption	MW	230

Continuous energy variation between 200 - 500 Gev

Upgradeable to 1 TeV

Artist's impression of the ILC tunnels



Graphic courtesy of Fermilab/Sandbox Studio

Superconducting RF

~17000 cavities

TESLA 9-cells 1.3 GHz SC niobium cavity

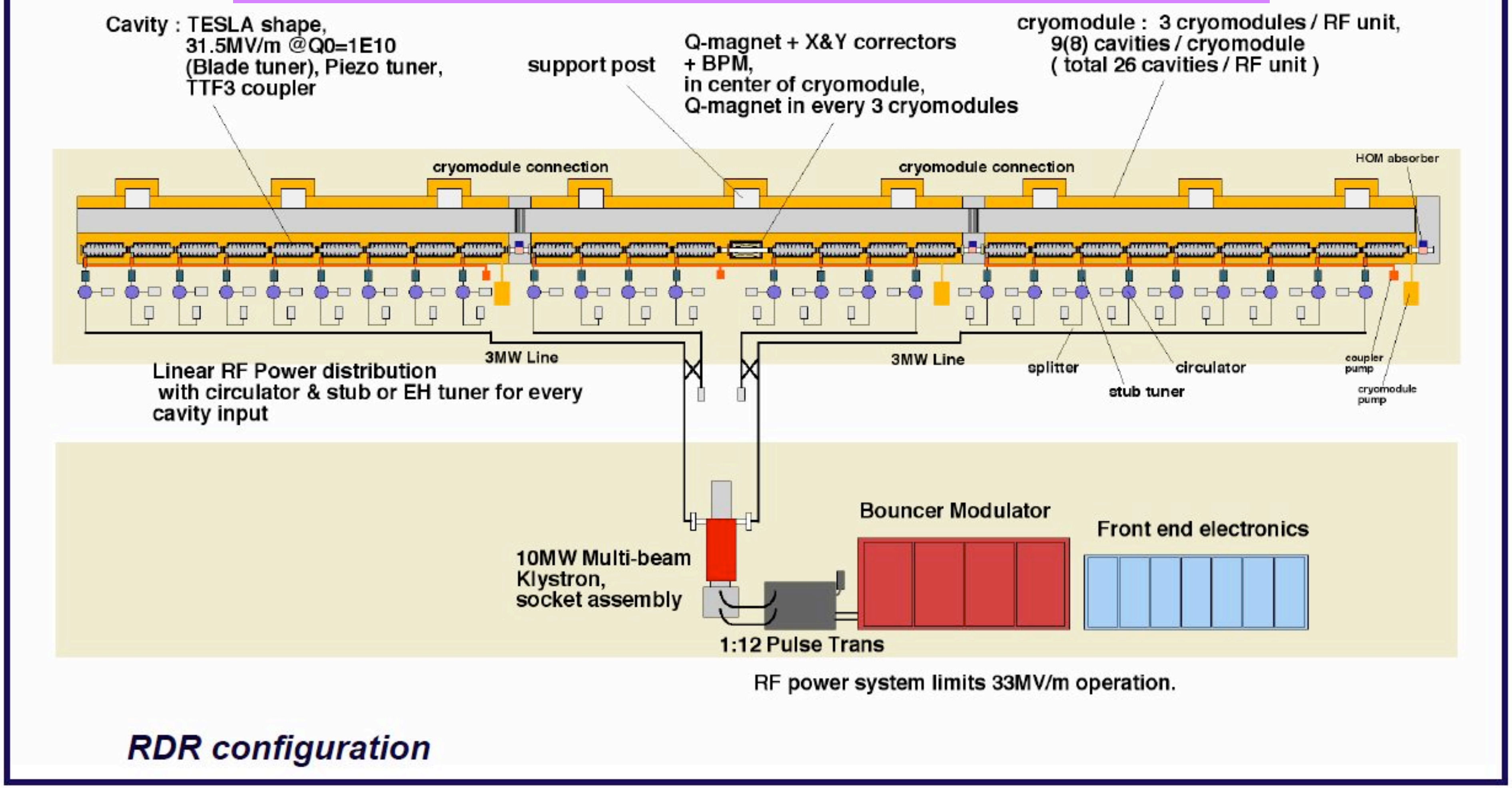
31.5 MV/m at $Q_0=1\cdot10^{10}$

Cryomodule installation at TESLA test facility

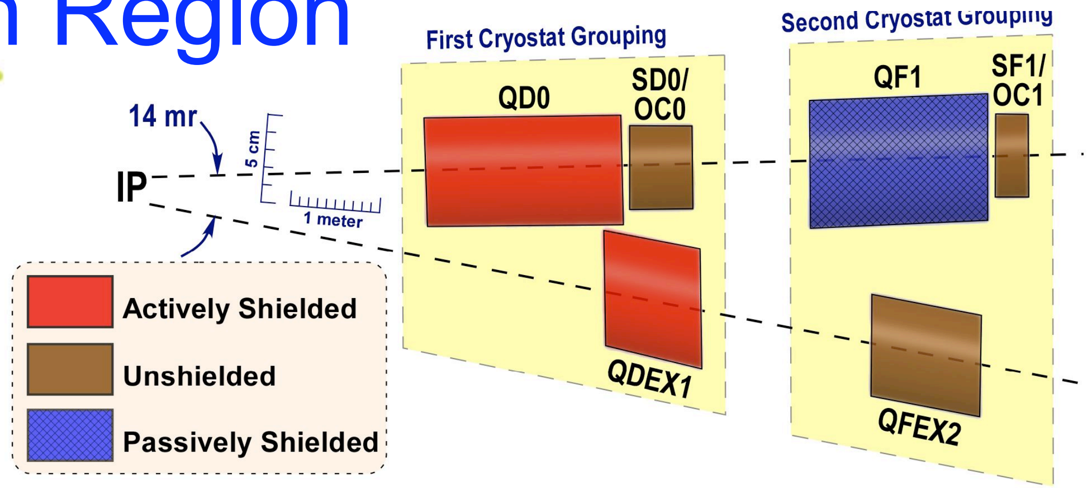
An inside view of a cryomodule

ILC Main Linac RF Unit

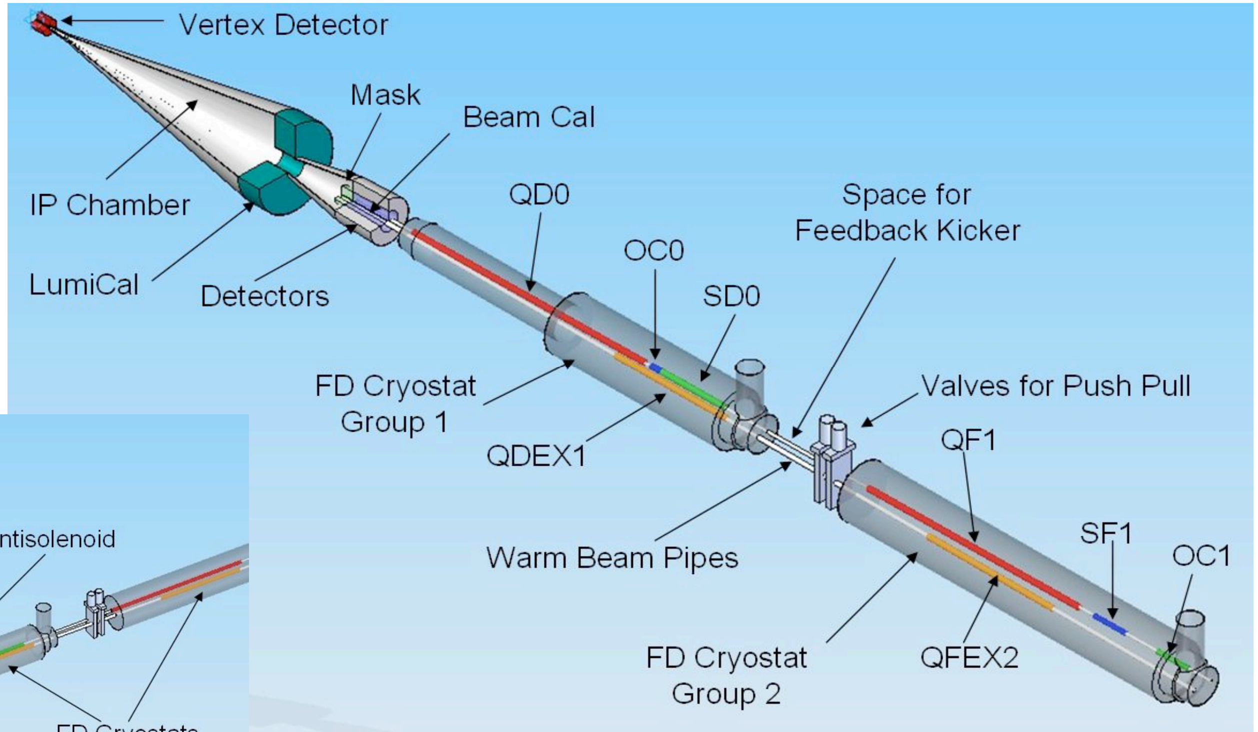
3 cryomodules, 9(8) cavities each, powered by a 10MW Multi-beam klystron

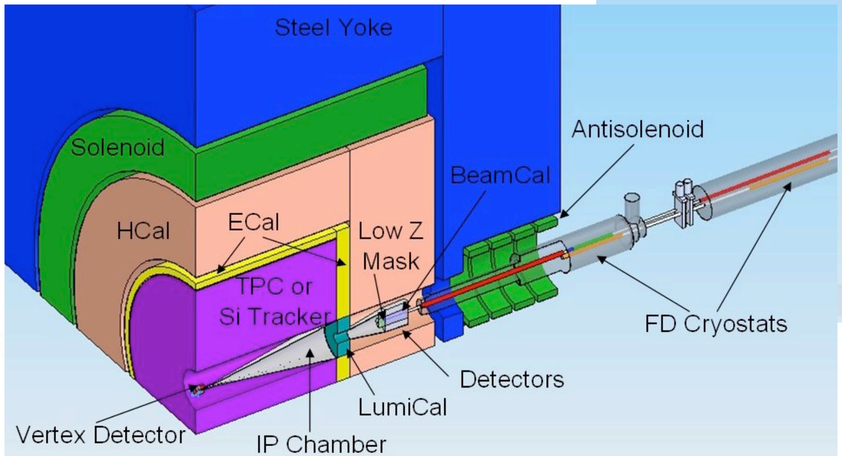


Interaction Region

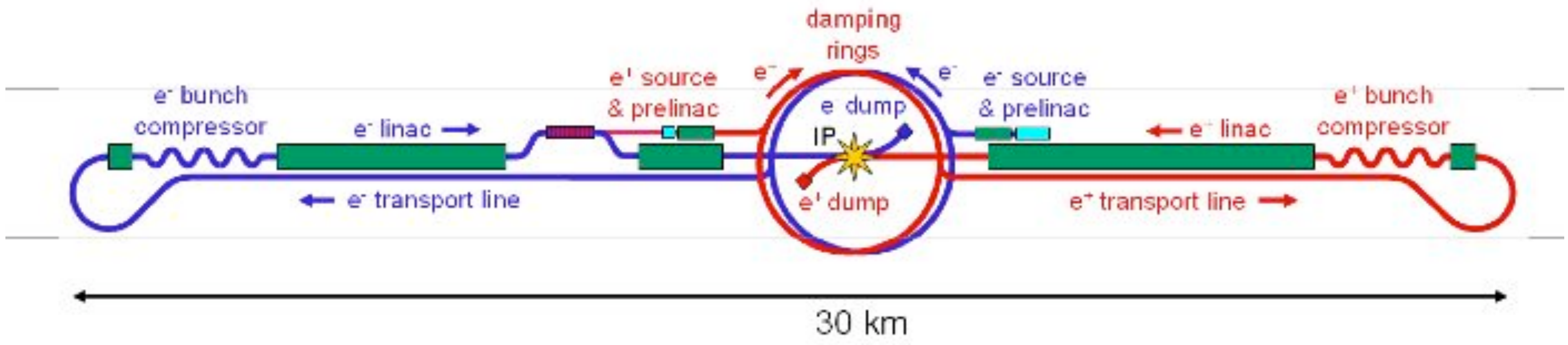


Final Focus Layout





Damping Ring Layout



Two 6.5 km, 5 GeV damping rings in a shared tunnel around the interaction region

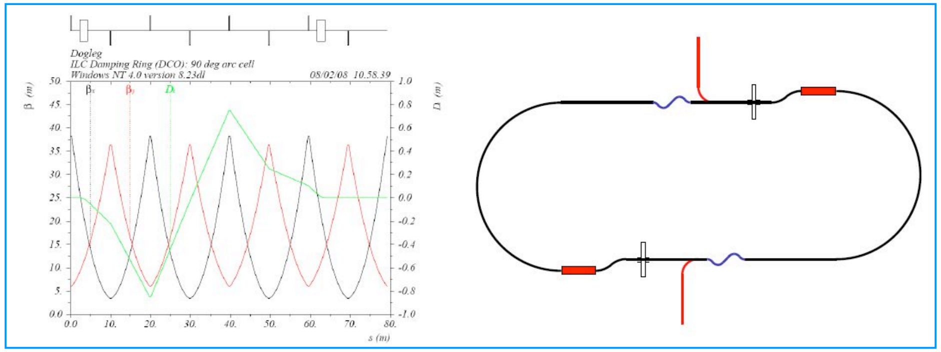
Damping Ring Requirements

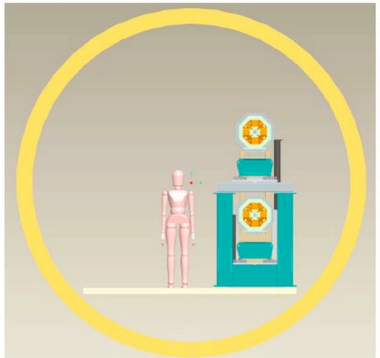
- Store 2700 - 5400 bunches per linac pulse
- Reduce the emittances by orders of magnitude in 200 ms (5 for e+ vertical emittance)
- extremely low emittance values
  - **ε_x = 0.6 nm**
  - **ε_y = 2 pm (minimum ever achieved)**
- Short transverse damping time τ = 21 ms
- Wigglers needed: total length ~ 200 m, peak field 1.67 T

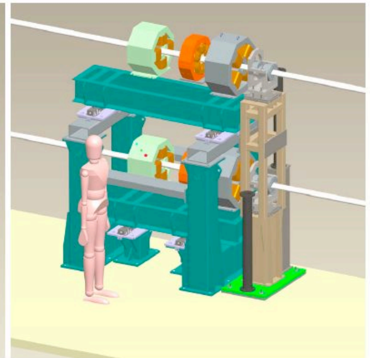
Damping Ring Main Challenges

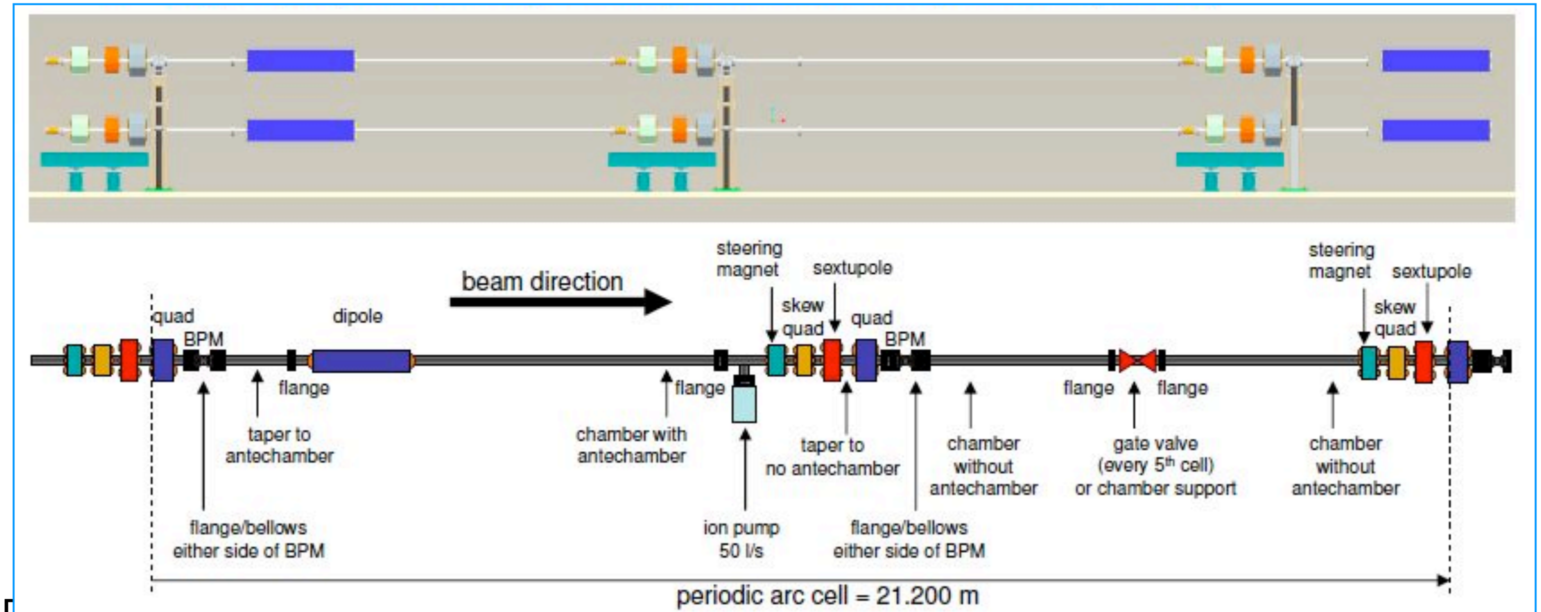
- Ultra low emittance
- Control of electron cloud effect in positron DR
  - **Vacuum chamber coating**
  - **Solenoids**
  - **Clearing electrodes**
- Control of the fast ion instability in the electron DR
  - **Pressure below 1 nTorr**
  - **Gaps in the ring fill pattern**
  - **Fast feedback systems**
- Developing a very fast rise and fall time kicker for single bunch injection and extraction in the ring.

Damping Ring Lattice Selected









RDR Reference Design Report

- The first major goal of the GDE was to define the basic parameters and layout of the machine, the Baseline Configuration. This was achieved at the Frascati GDE Meeting (INFN,December 2005).

- The second major milestone has been reached with the presentation of the RDR with cost estimate, at the Beijing GDE Meeting, IHEP, 4-7 February 2007 (http://www.linearcollider.org/cms/)
  - **Executive summary**
  - **Physics at the ILC**
  - **Accelerator**
  - **Detectors**

GDE Plan – Major Elements

- GDE R&D program for the next phase will follow the *"Technical Design Phase R&D Plan"*
- A two stage ILC Technical Design Phase (TDP-1 2010 and TDP-2 2012 is proposed
  - **R&D program to demonstrate gradient, electron cloud, RF unit, etc.**
  - **Minimal Machine Approach to make cost effective design**
  - **Conventional Facilities Cost Drivers (1 vs 2 tunnels, shallow vs deep siting, technical drivers like water systems.**
- Develop a Project Implementation Plan

R&D Test Facilities

Test Facility	Deliverable
ATF (KEK)	**Generation of 2 pm-rad low emittance beam**
CESR-TA (Cornell)	***Electron cloud mitigation studies:*** **Re-configuration of CESR as low-emittance e-cloud test facility**
ATF-2 (KEK)	***Final Focus Optics and Stabilisation Demonstration:*** **35 nm beam size at focal point**
TTF/FLASH (DESY)	**Full 9 mA, 1 GeV, high-repetition rate operation**
TTF/FLASH (DESY) **&** **STF** (KEK) **&** **ILCTA-NML** (FNAL)	**Linac RF Unit demonstration with beam**

Global Plan for SCRF R&D

Calender Year	2007	2008	2009	2010	2011	2012
Technical Design Phase	TDP-1			TDP-2		
Cavity Gradient R&D to reach 35 MV/m		Process Yield > 50%		Production Yield >90%		
Cavity-string test: with 1 cryomodule		Global collab. For <31.5 MV/m>				
System Test with beam 1 RF-unit (3-modulce)		FLASH (DESY)			STF2 (KEK) NML (FNAL)	

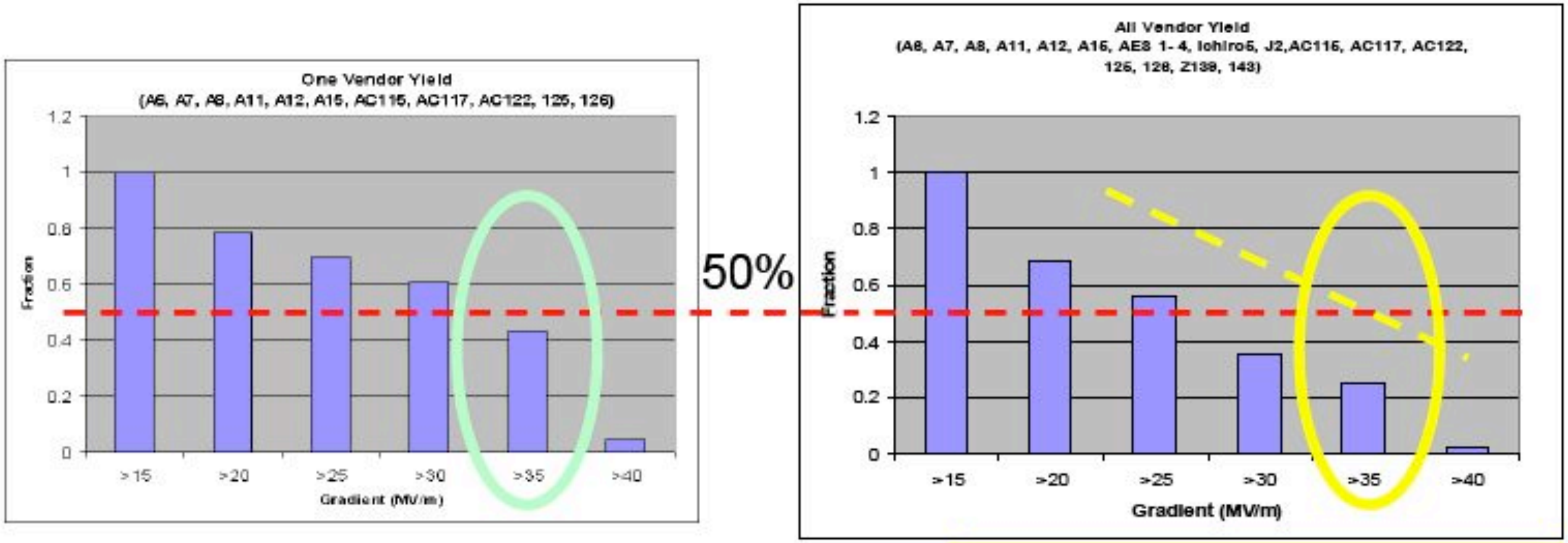
Global Yield of Cavities (November 2008) and Expectation

23 tests, 11 cavities

One Vendor

48 Tests, 19 cavities

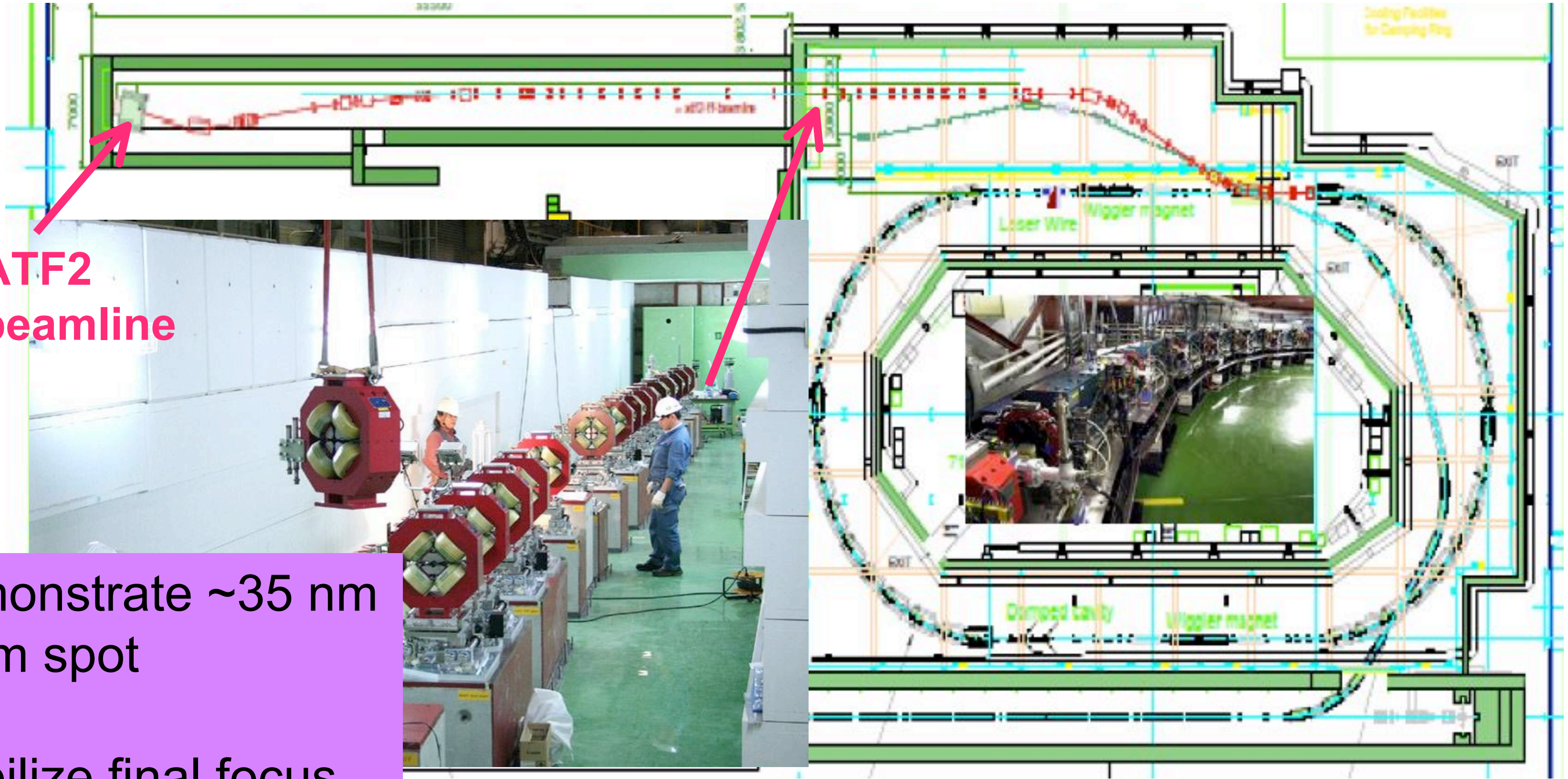
ACCEL, AES, Zanon, Ichiro, Jlab



45% yield at 35 MV/m being achieved by cavities with a qualified vendor

H. Padamsee, TTC-08 (IUAC), ILC-08 (Chicago)

ATF2: Beam delivery model



Demonstrate ~35 nm beam spot

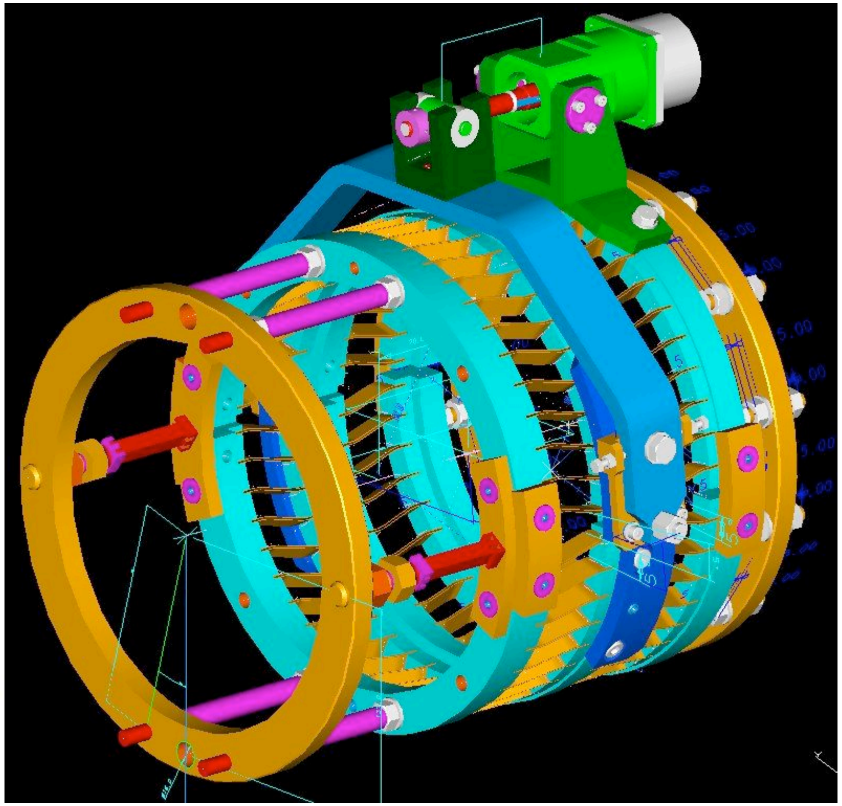
Stabilize final focus

A scaled down version of ILC Beam Delivery System

ATF collaboration: >200 scientists, 20 institutions worldwide

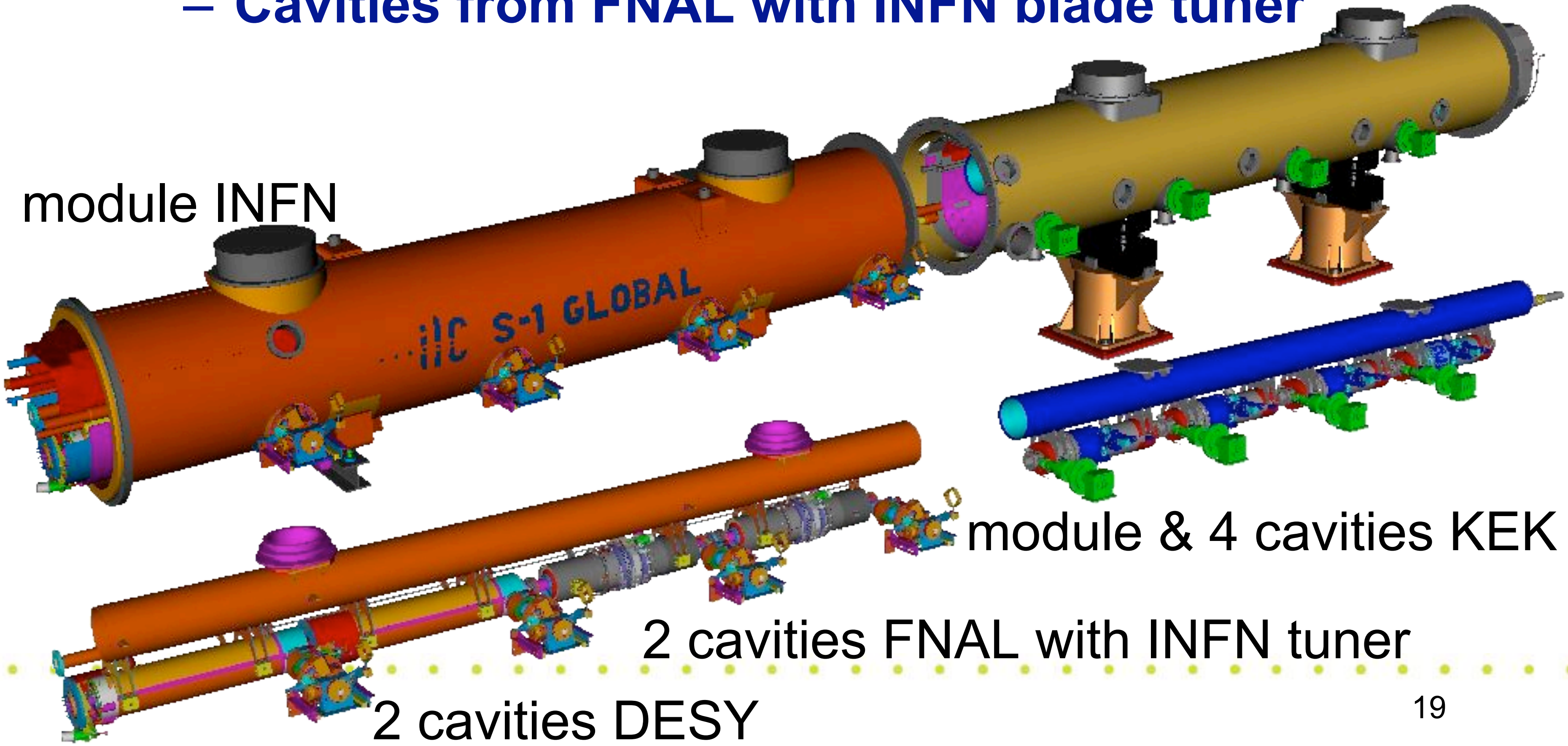
INFN SCRF

- Involvement in many SRF Linac activities
  - Development, in collaboration with Fermilab and KEK, of new ILC cryomodules based on the TTF modules designed and realized by INFN-Milano with Italian industry
  - Blade Tuners: coaxial tuners designed by INFN Milano will be used for ILC cavities



S1-Global a KEK

- Test at KEK of a cryomodule with cavities from FNAL, DESY and KEK
  - **Design, and fabbrication in Italy**
  - **Cavities from FNAL with INFN blade tuner**



ILC - LNF Damping Ring

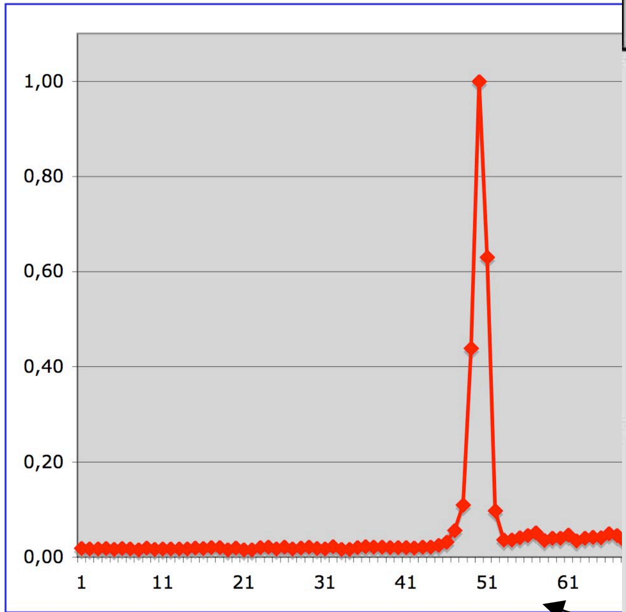
- **Fast Kickers for DR injection and extraction** (Coordination of the DR Design in the GDE)
- Studies of the e-cloud instability at DAFNE
- R&D on digital feedback systems for the DR
- Specifications of the 650 MHz radiofrequency system of the DR

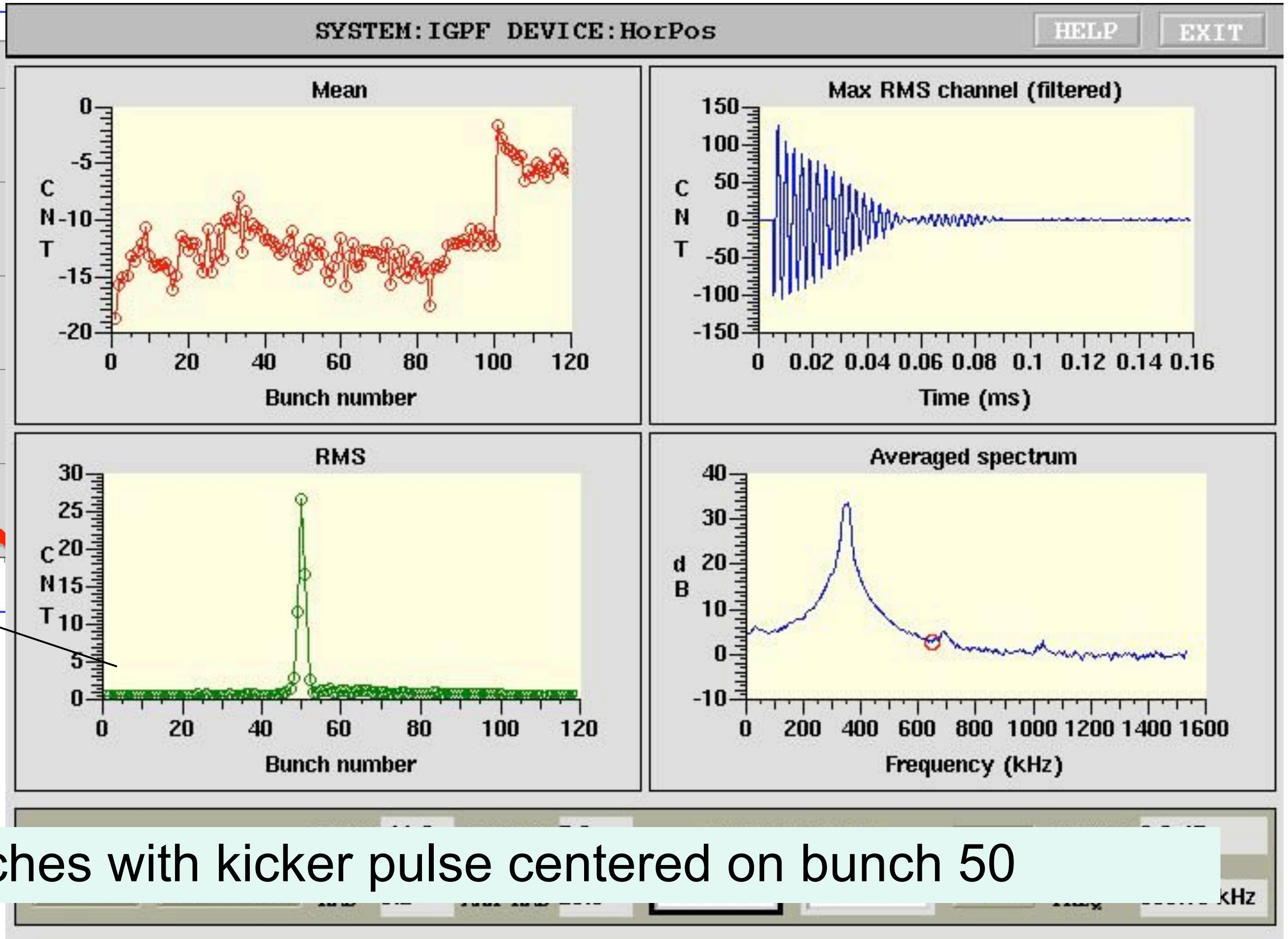
Damping Ring: fast kickers activity

- Injection and extraction kickers are one of the most critical issues since the bunch distance and ring circumference are related to kicker pulse duration
- R&D programs are in progress in laboratories worldwide both on fast pulsers and on stripline electrodes
- Requirements:
  - **total pulse duration: < 6.2 ns for 3 ns bunch distance;**
  - **good uniformity;**
  - **low impedance;**
  - **up to 6 MHz repetition rate**

e^+ beam oscillation with fast kick

Measured by diagnostics of the horizontal digital feedback system.





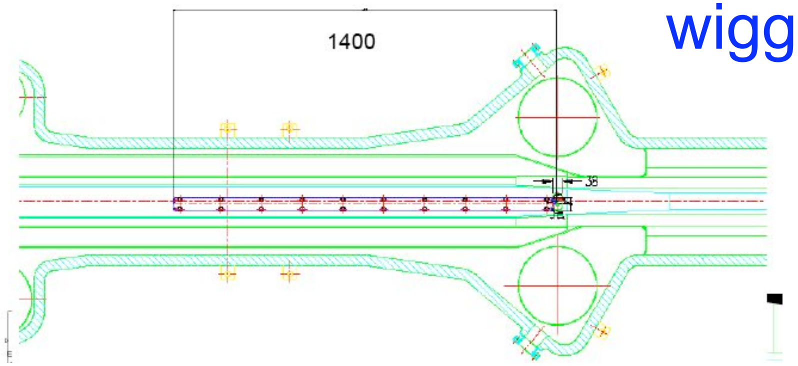
Bunch distance 2.7 ns

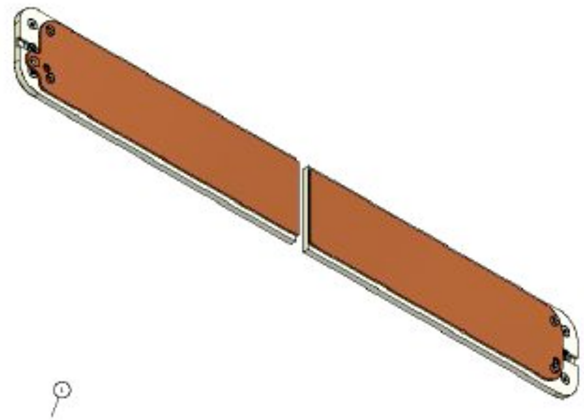
100, of 120, stored bunches with kicker pulse centered on bunch 50

Fast Kickers installed in DAFNE rings
Pulse duration < 12 ns

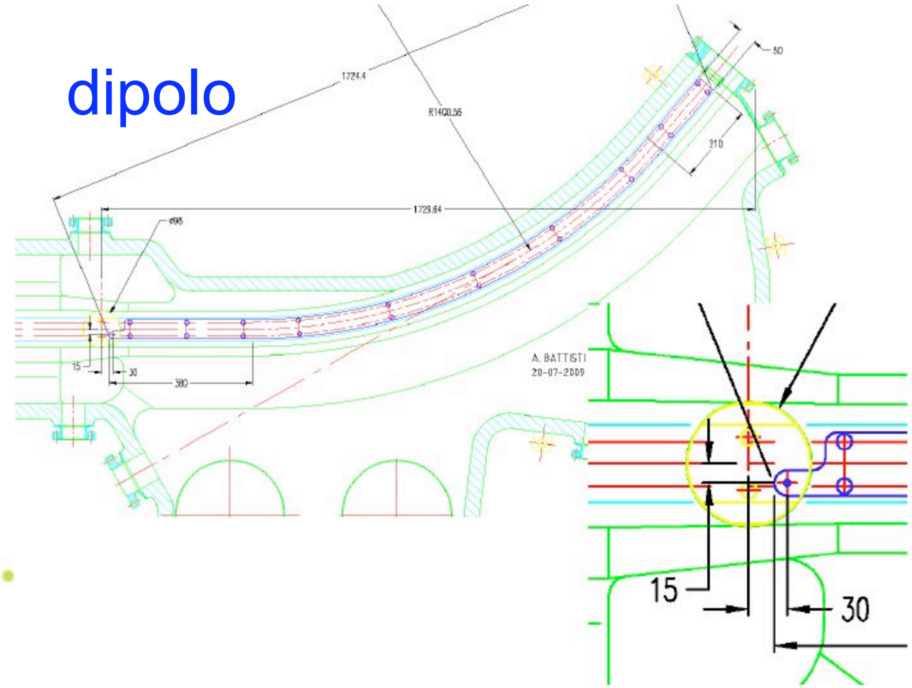
Clearing Electrodes to reduce the electron cloud will be installed in the DAFNE dipoles and wigglers

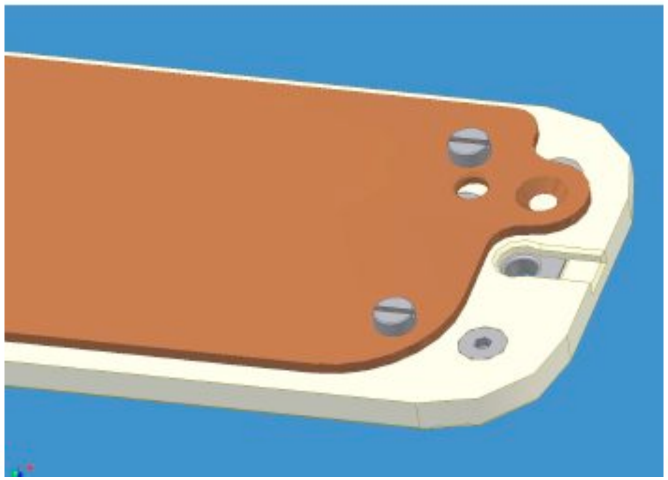
wiggler



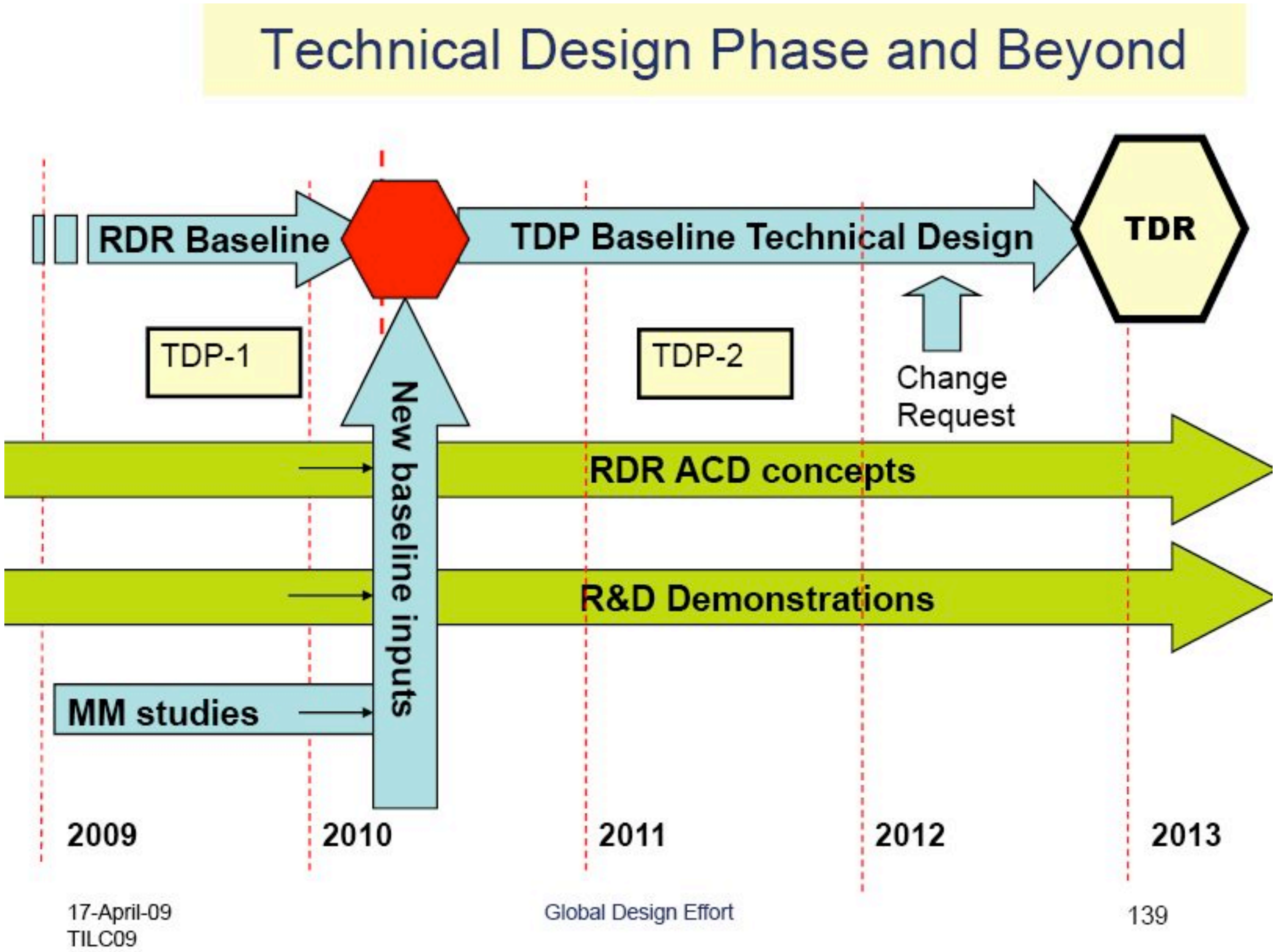


dipolo





The GDE schedule for creating a new baseline for the Technical Design Phase.



Goal of evolving the RDR baseline configuration to one more optimised for cost to risk to performance

CLIC Compact Linear Collider

If LHC physics demands a > 1 TeV machine:

⇒**CLIC** may be the answer on a longer time scale, depending on "feasibility" study for $E_{cm} < 3$ TeV

⇒Developed @ ***CERN***

⇒***Originally NC 30 GHz***, 150 MV/m: recently changed parameters to 12 GHz and 100 MV/m to reduce cost and better utilize GLC/NLC R&D

⇒Based on a ***two-beam accelerator concept***:

is an efficient way to transform rf frequency from long-pulse low-frequency in short-pulse high-frequency and thereby drive high gradients

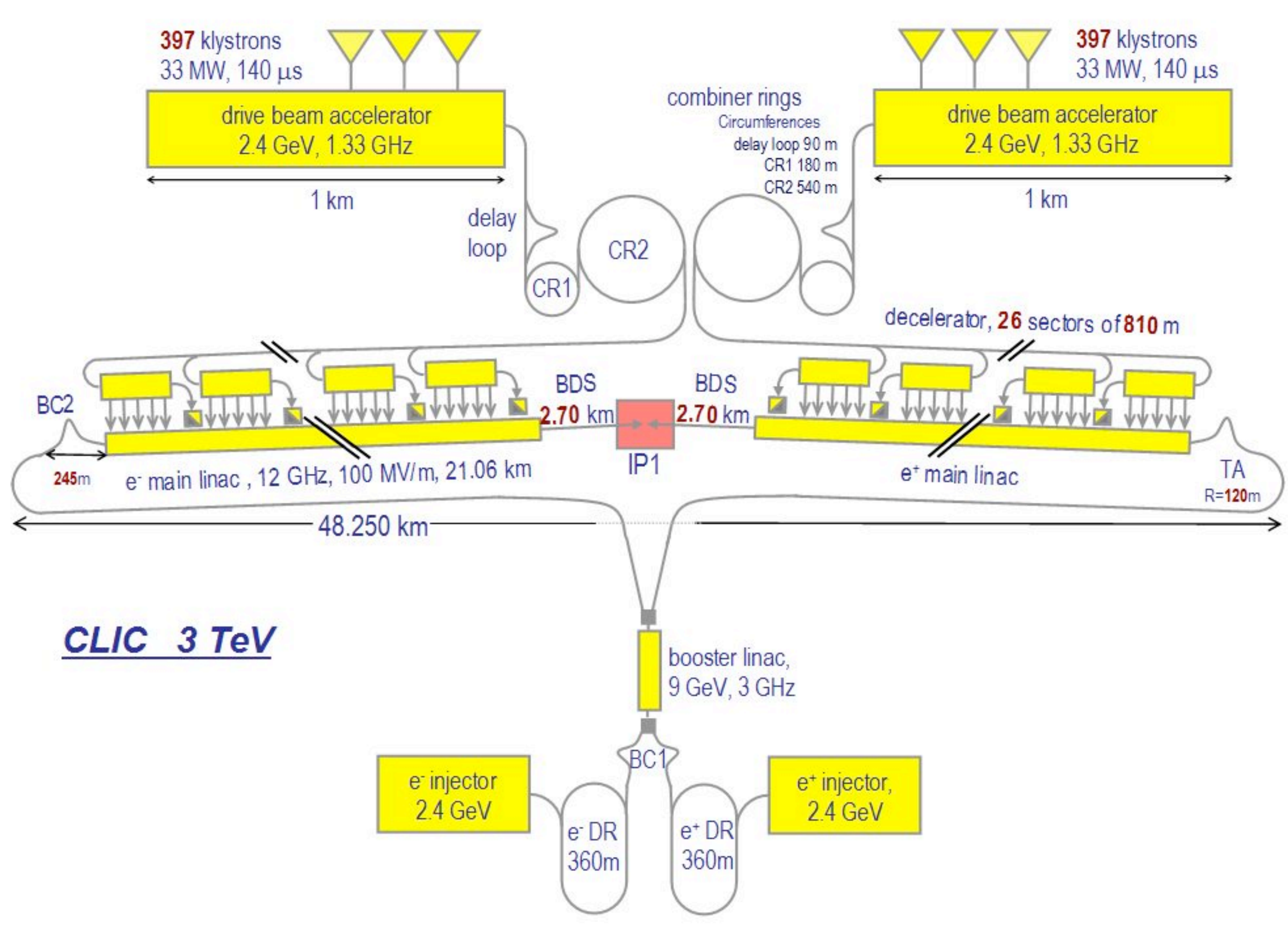
Concept is elegant but still waiting for complete demonstrations(CTF3 test facility)

⇒***Developed parameters from 500 GeV → 3TeV***

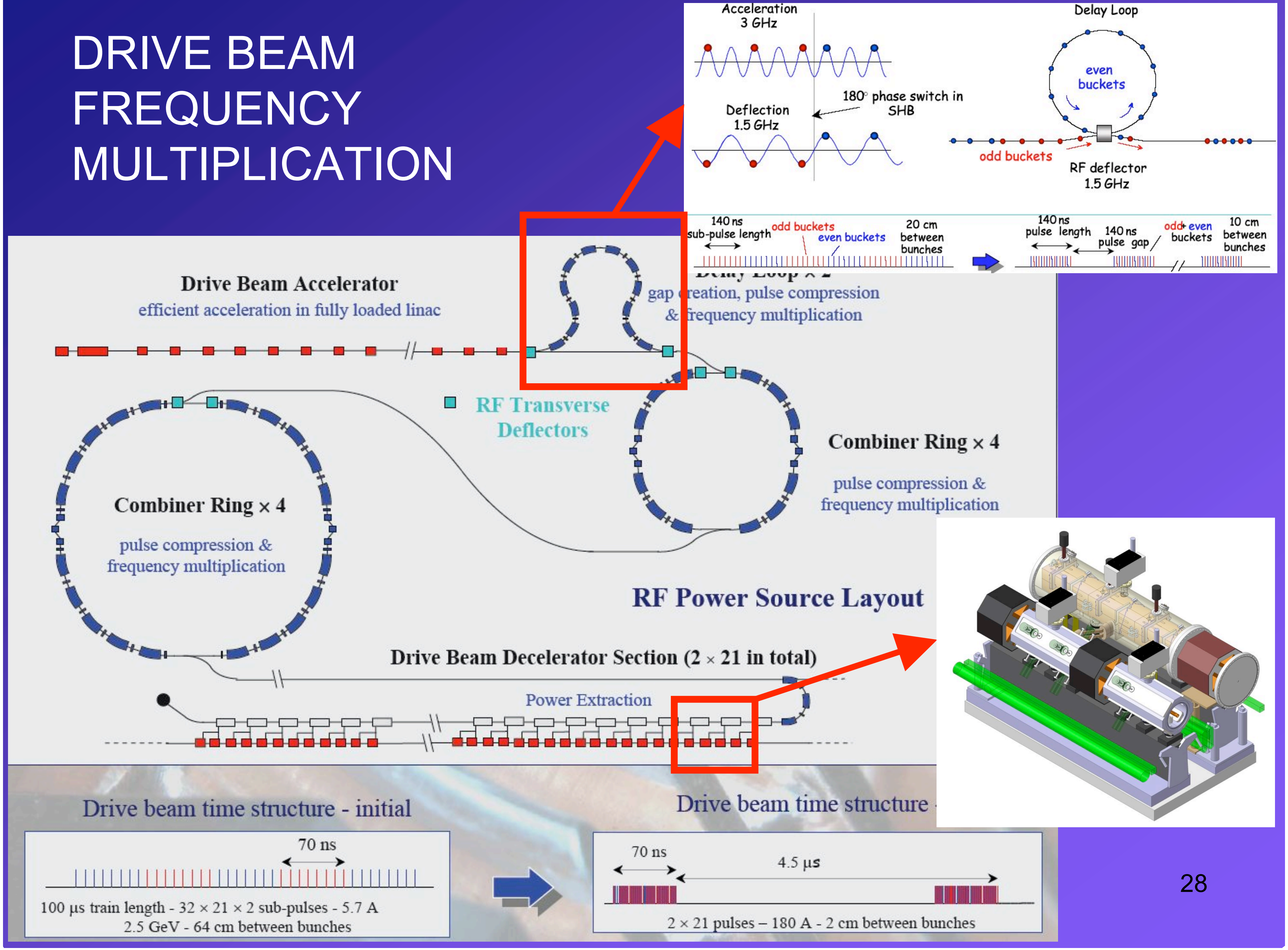
Basic Features of CLIC

- **High acceleration gradient (100 MV/m)**
  - **"Compact" collider - overall length < 50 km @3TeV**
  - **Normal conducting accelerating structures**
  - **High RF frequency (12 GHz)**
- **Two-Beam Acceleration Scheme**
  - **Capable to reach high frequency**
  - **Cost-effective & efficient (~ 10% overall)**
  - **Simple tunnel, no active elements**
- **Central injector complex**
  - **"Modular" design, can be built in stages**

CLIC Schematic



DRIVE BEAM FREQUENCY MULTIPLICATION

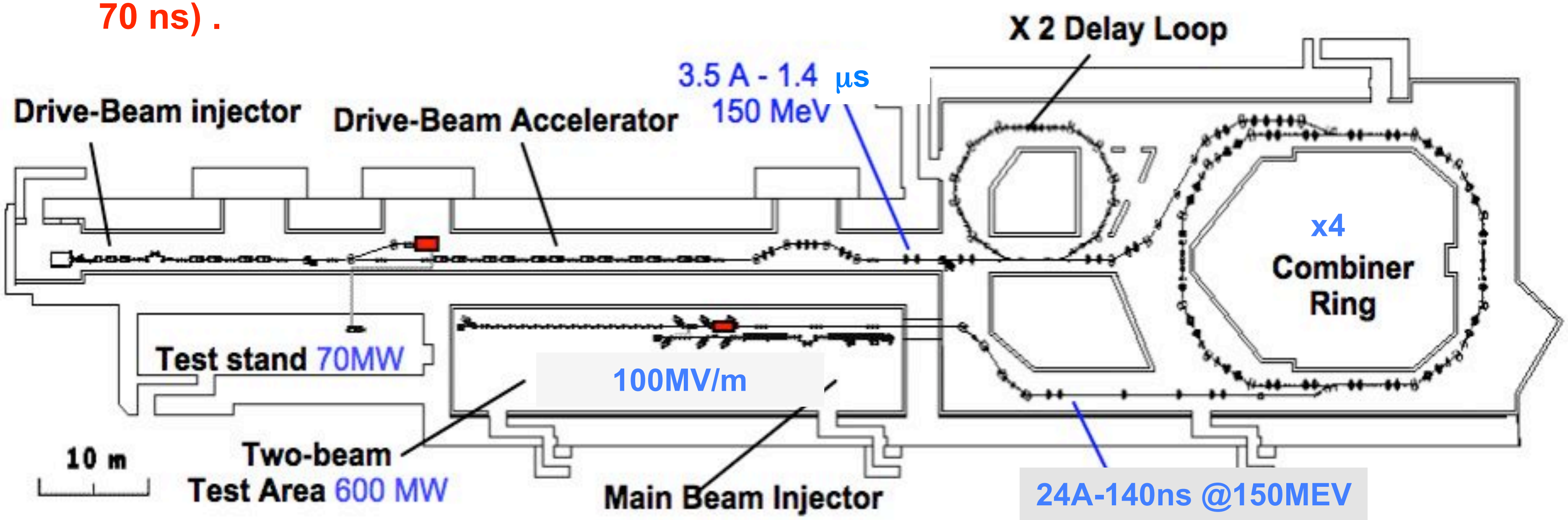


CLIC Main Parameters

Center-of-mass energy	CLIC 500 G		CLIC 3 TeV	
Beam parameters	Conservative	Nominal	Conservative	Nominal
Accelerating structure	502		G	
Total (Peak 1%) luminosity	$0.9(0.6)\cdot10^{34}$	$2.3(1.4)\cdot10^{34}$	$2.7(1.3)\cdot10^{34}$	$5.9(2.0)\cdot10^{34}$
Repetition rate (Hz)	50			
Loaded accel. gradient MV/m	80		100	
Main linac RF frequency GHz	12			
Bunch charge10^9	6.8		3.72	
Bunch separation (ns)	0.5			
Beam pulse duration (ns)	177		156	
Beam power/beam MWatts	4.9		14	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)	3/40	2.4/25	2.4/20	0.66/20
Hor/Vert FF focusing (mm)	10/0.4	8 / 0.1		4 / 0.1
Hor./vert. IP beam size (nm)	248 / 5.7	202 / 2.3	83 / 1.1	40 / 1
Hadronic events/crossing at IP	0.07	0.19	0.75	2.7
Coherent pairs at IP	10	100	$5.\ 10^7$	$3.8\ 10^8$
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	129.4		415	

CTF3 Motivation and Goals

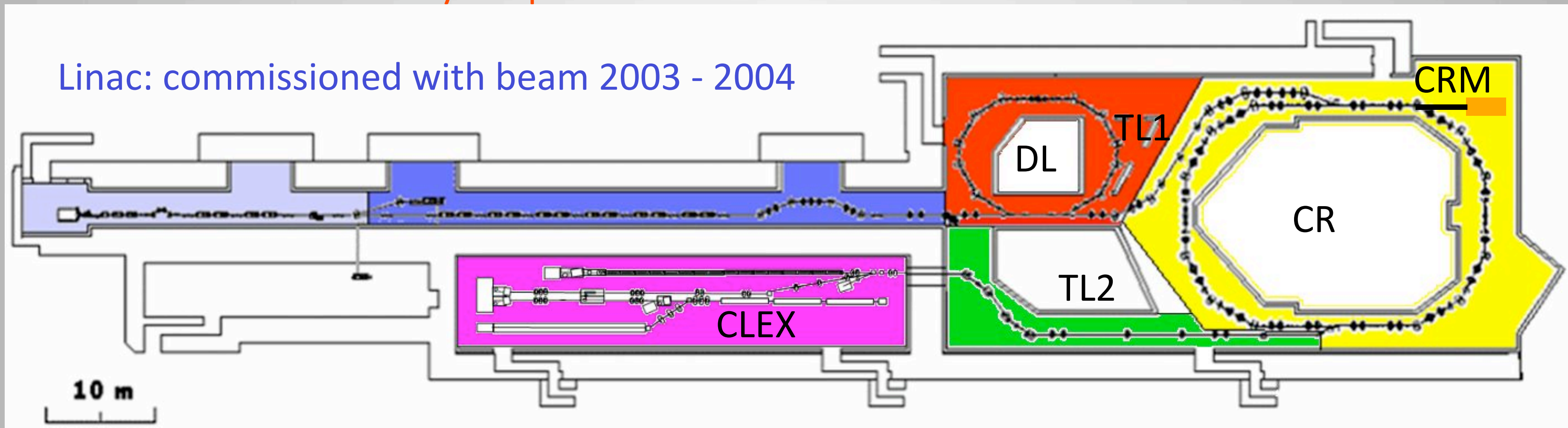
- Build a small-scale version of the CLIC RF power source, in order to demonstrate:
  - full beam loading accelerator operation
  - electron beam pulse compression and frequency multiplication using RF deflectors
- Provide the 12 GHz RF power to test the CLIC accelerating structures and components at and beyond the nominal gradient and pulse length (100 MV/m for 70 ns) .



CLIC Test Facility 3

TL1 & CRM commissioned fall 2006

Delay Loop: commissioned with beam 2005-2006



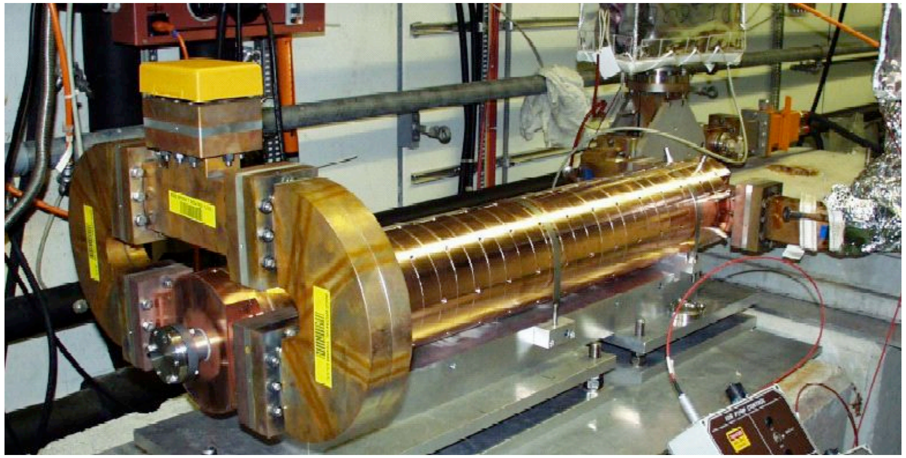
CR commissioning 2007-2008

2009: 3A beam to the end of Two Beam Test Stand

- First test of two-beam lines

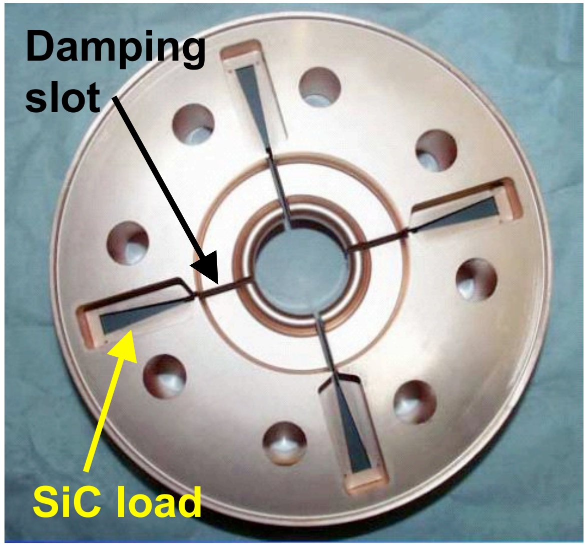
TL2 and TBTS commissioning started August 2008

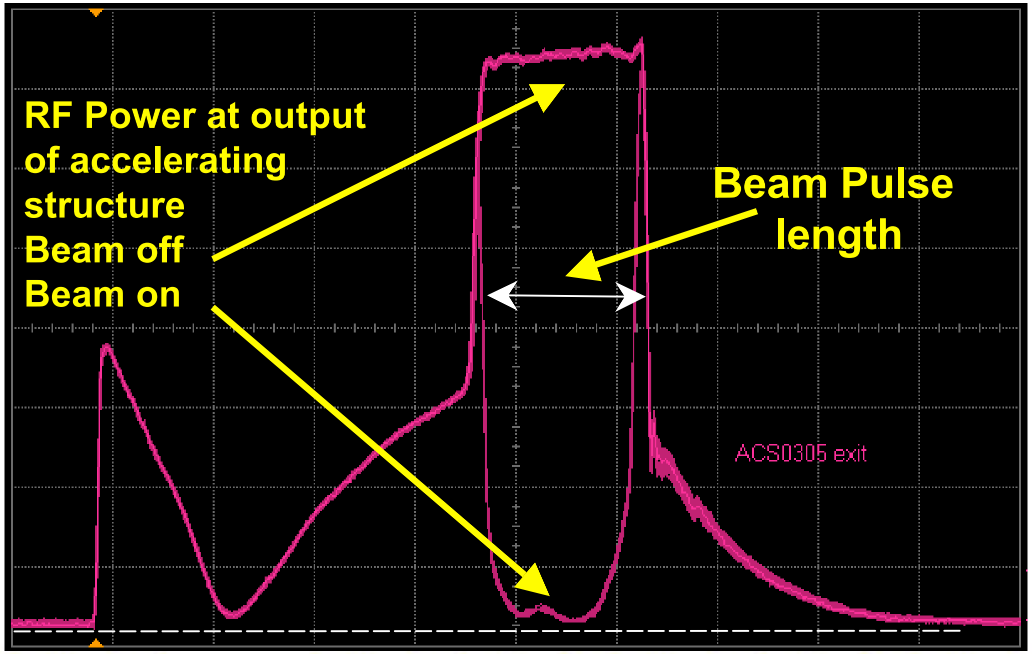
First "Full" Beam Loading operation in CTF3



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

2003

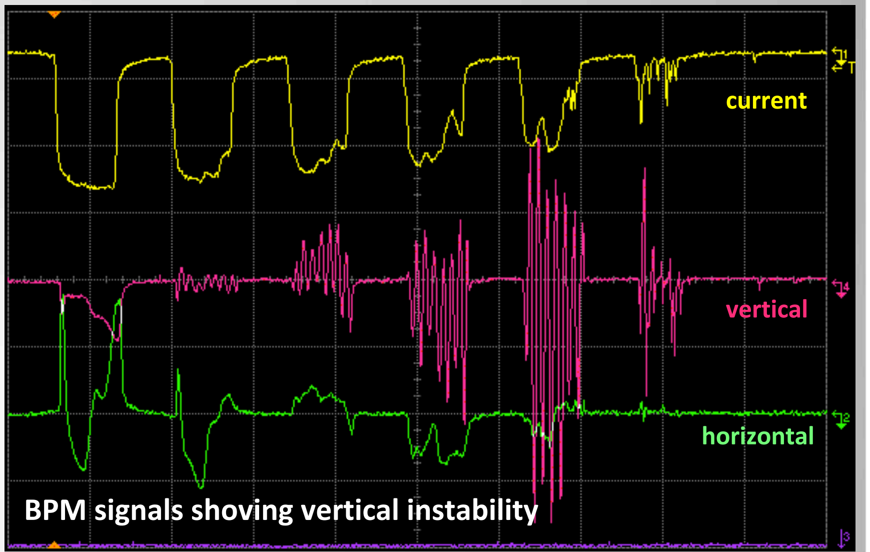


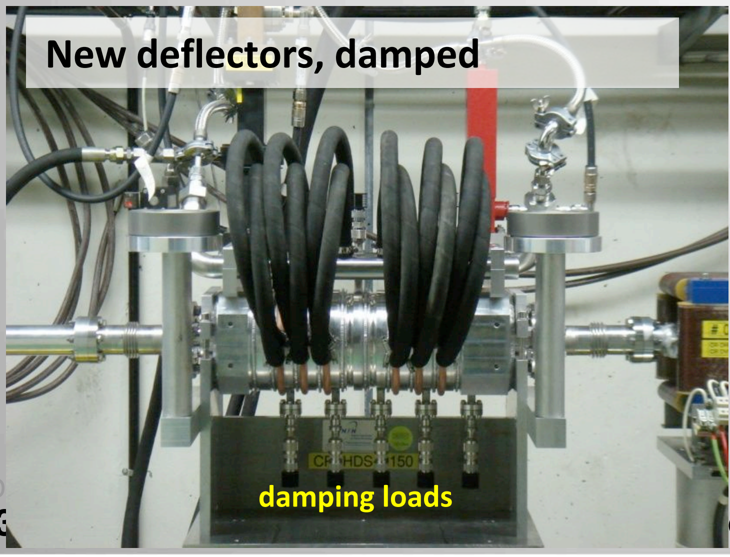


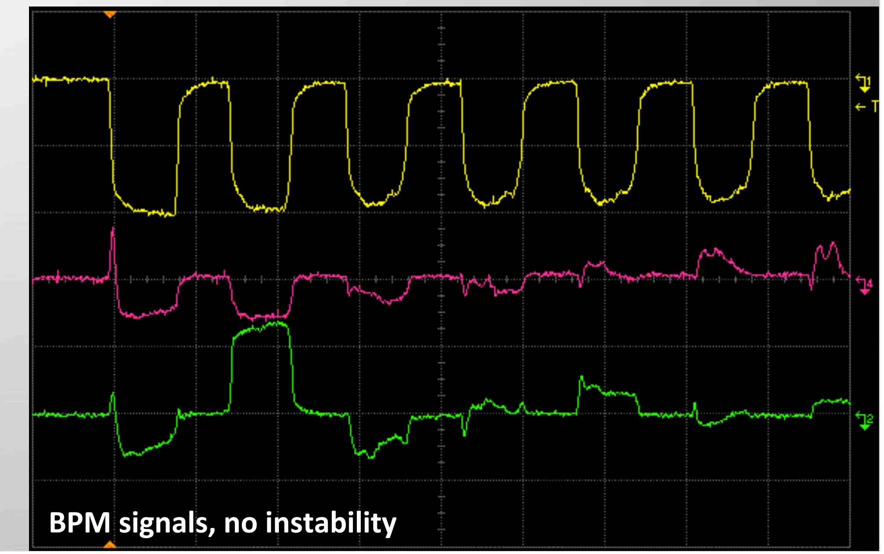
Beam current	4 A
Beam pulse length	1.5 μs
Power input/structure	35 MW
Ohmic losses (beam on)	1.6 MW
RF power to load (beam on)	0.4 MW

RF-to-beam efficiency ~ 94%

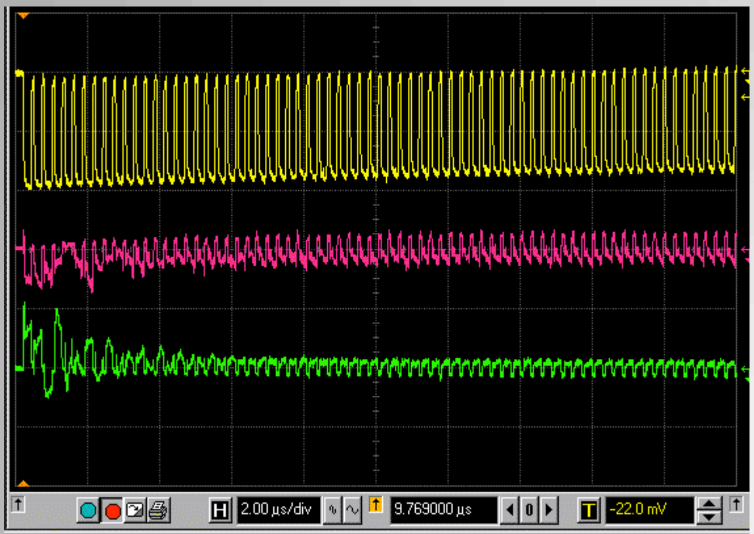
Combiner Ring Commissioning 2008
Instability Solved





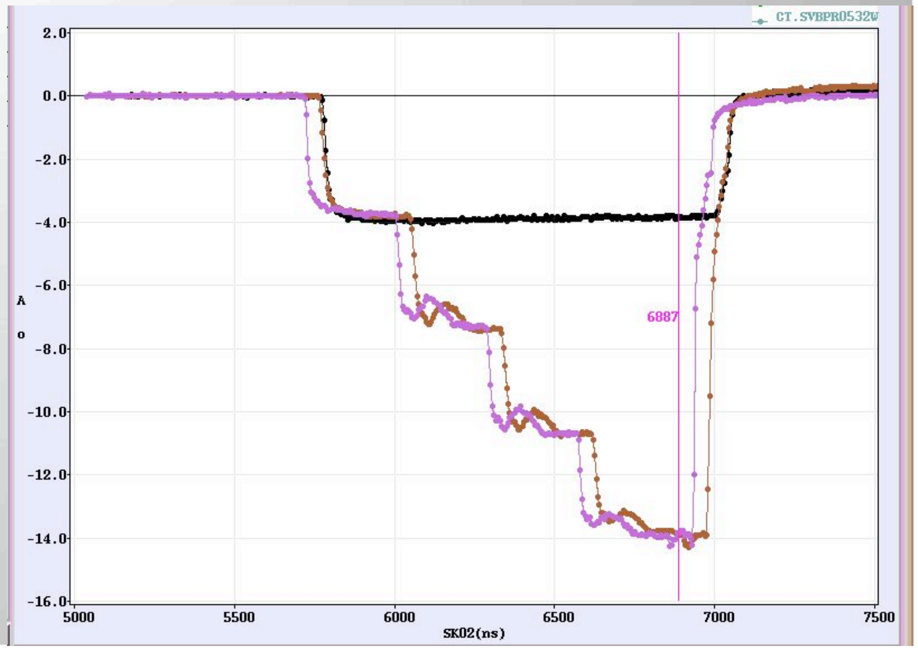


Combiner Ring Commissioning



Thousand turns without observing beam losses!

- We solved many of the problems of which the most important was the instability
  - New deflectors were installed mid of September
  - Gun seems to be stable now
- This brought immediate effect in form of the full recombination factor 4

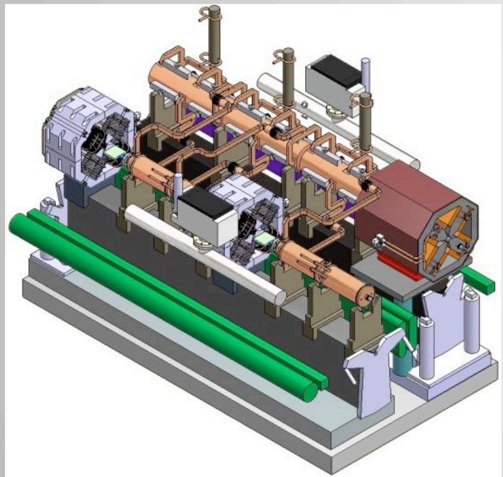


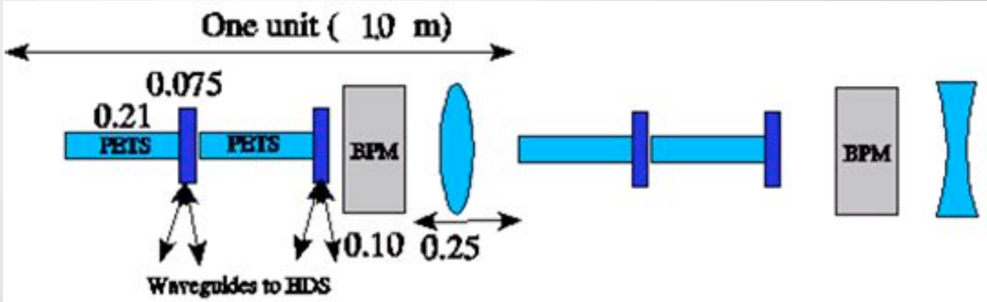
Date Event

PETS: nominal usage in CLIC

- Reminder: PETS is the generator of the CLIC RF power
- In each Decelerator sector the 100A CLIC Drive Beam pass through ~1500 PETS, 21 cm long, each producing 136 MW RF power

I. Syratchev, D. Schulte, E. Adli and M. Taborelli, "High RF Power Production for CLIC", *Proceedings of PAC 2007*





- The CLIC Decelerator beam dynamics has been studied extensively, e.g.

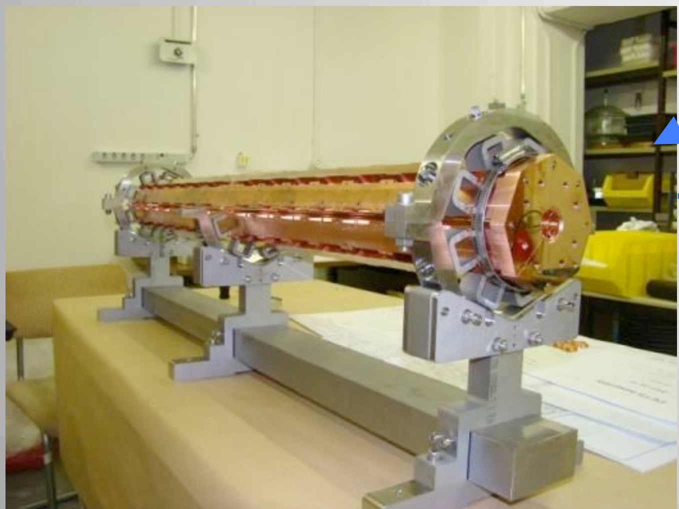
E. Adli,D. Schulte and I. Syratchev, “Beam Dynamics of the CLIC Decelerator”, *Proceedings of XBAND Workshop’08*

- TBTS: provides the **first beam tests** of the 12 GHz PETS

Two Beam test Stand

All hardware installed !
Commissioning with beam ongoing
Beam in both lines up to end !

PETS (CERN) was installed in October, first accelerating structure in 2009



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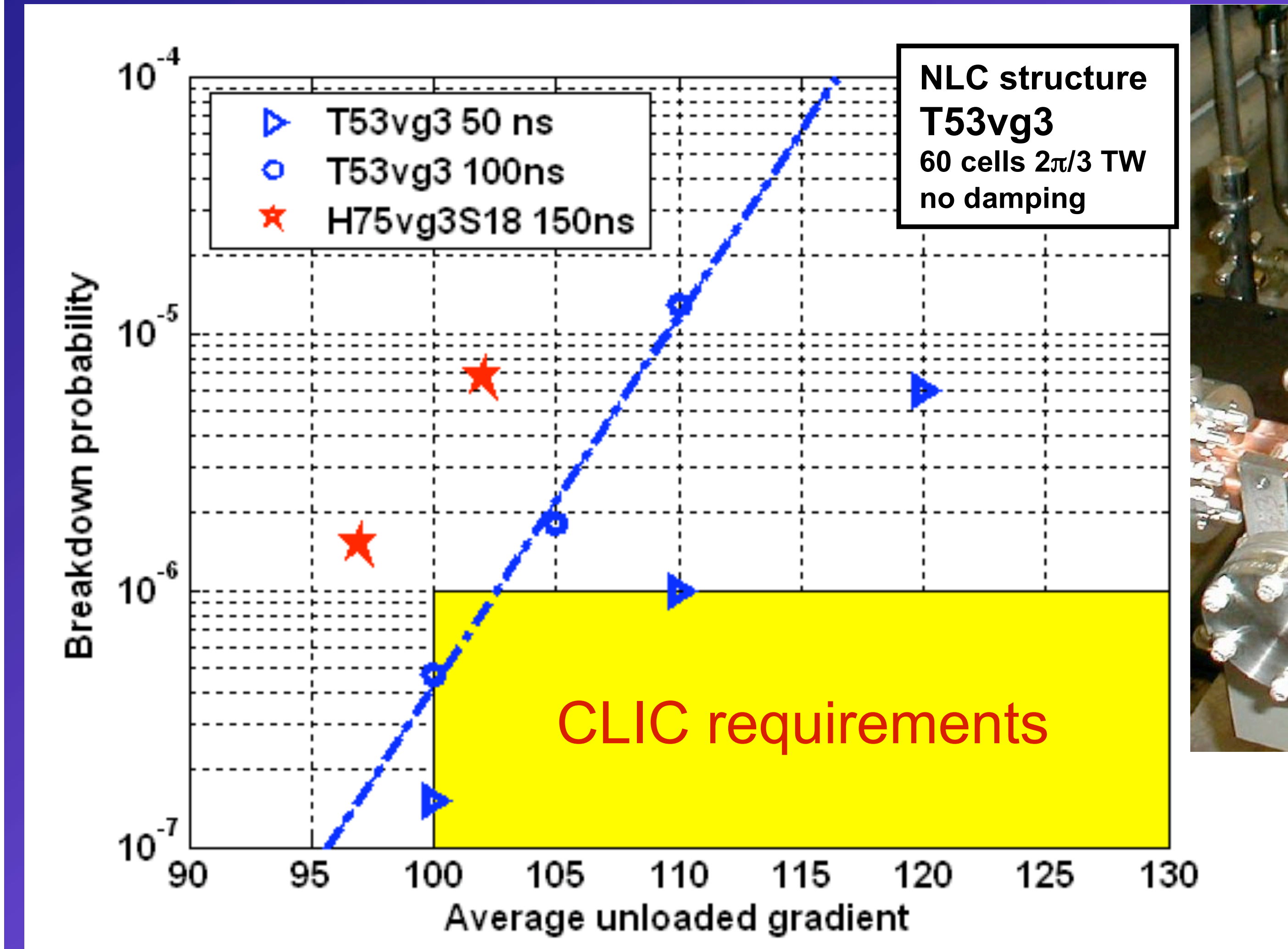
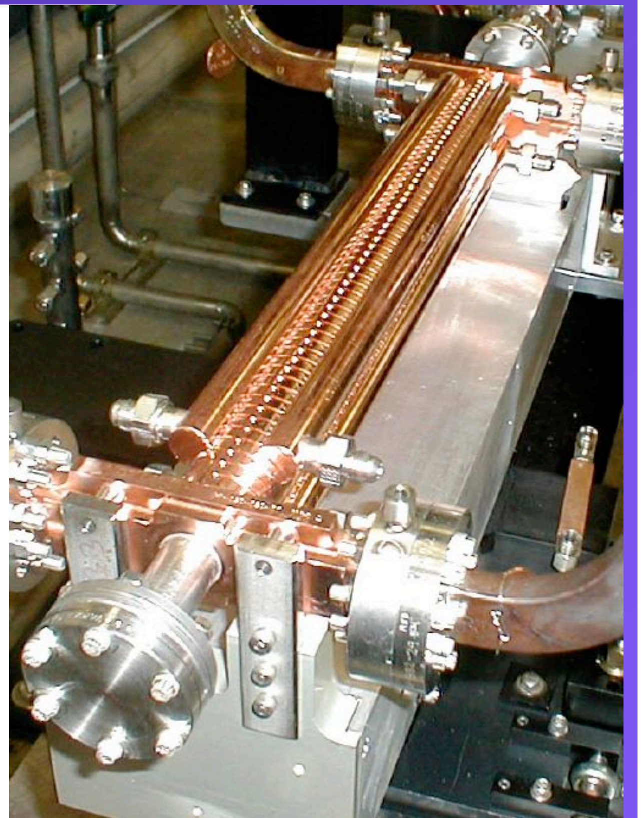
11.4 GHz High-Power test results

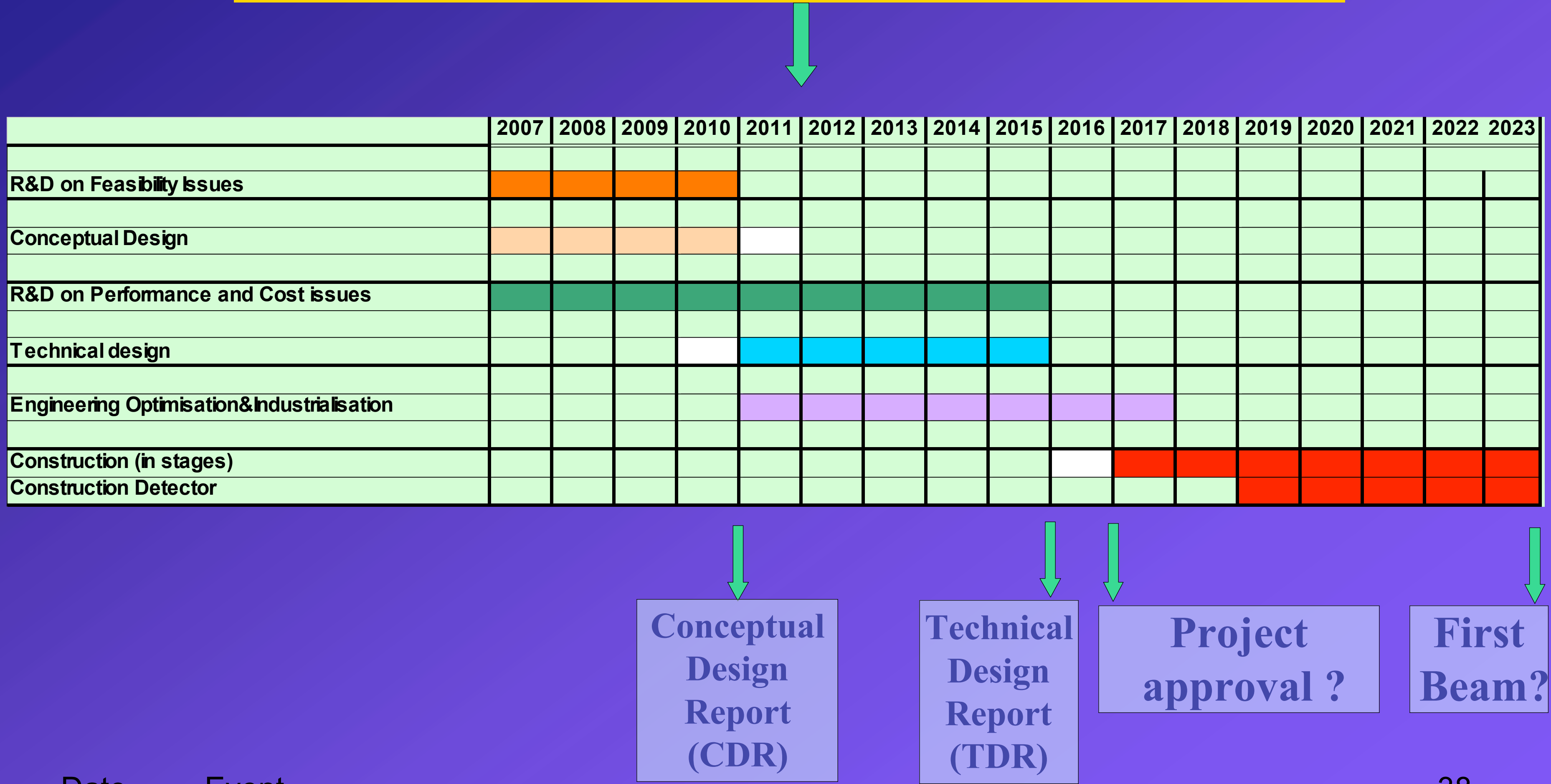
Recent SLAC High-Power test results – 11.4 GHz





Tentative long-term CLIC scenario

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



ILC/ CLIC Collaboration

– Working Groups with joint leadership:

- Accelerator Technical Areas
  - Beam Delivery System (BDS) & Machine Detector Interface (MDI)
  - Positron Generation
  - Damping Rings
  - Beam Dynamics
- Physics / Detectors
- Civil Engineering & Conventional Facilities
- Costing

ILC/ CLIC Workshop at CERN late 2010

ILC/ CLIC Collaboration

ILC and CLIC are proceeding toward a closer collaboration

The development of both approaches is necessary in order to provide the best possible choice when the results from the LHC will be available