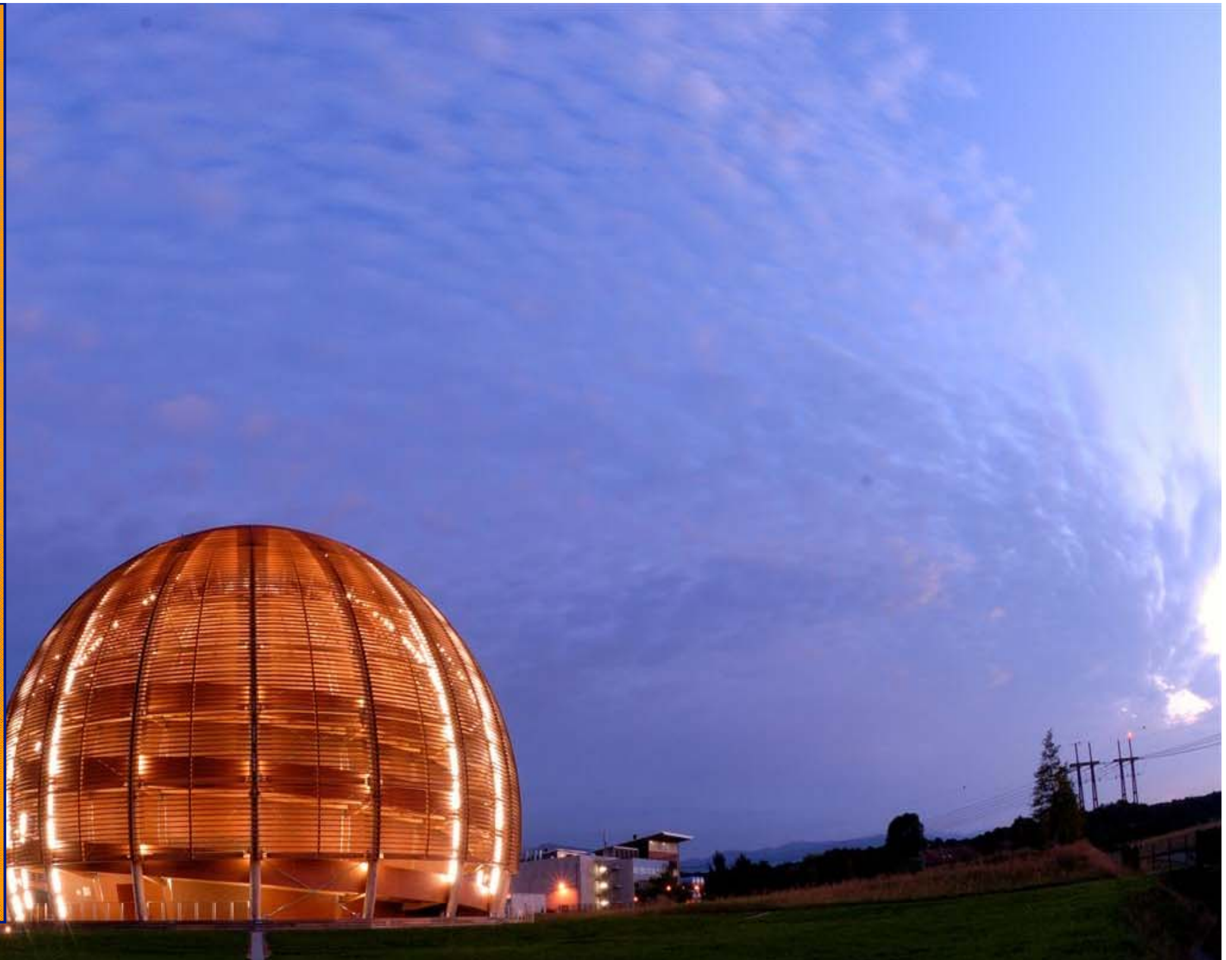
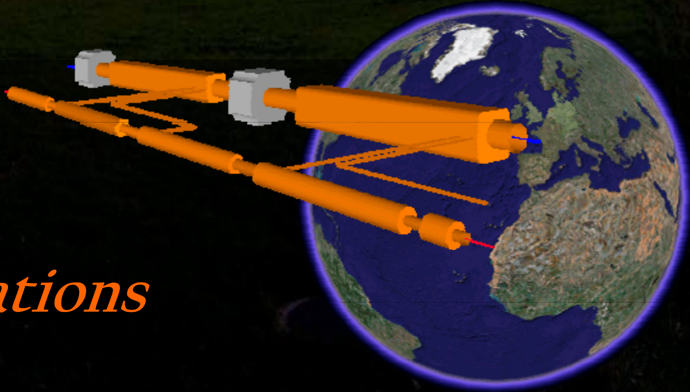
Talk outline

- **CLIC scheme –**
  - **Description, Challenges,**
  - **Feasibility issues**
- **X-band structures developments**
  - **Operational facilities**
  - **Industrial applications**
- **Collaborations**
  - **Present contributions**
  - **Opportunities in the future**
- **Conclusion**





CLIC Overview and opportunities for future collaborations

J.P.Delahaye - CERN

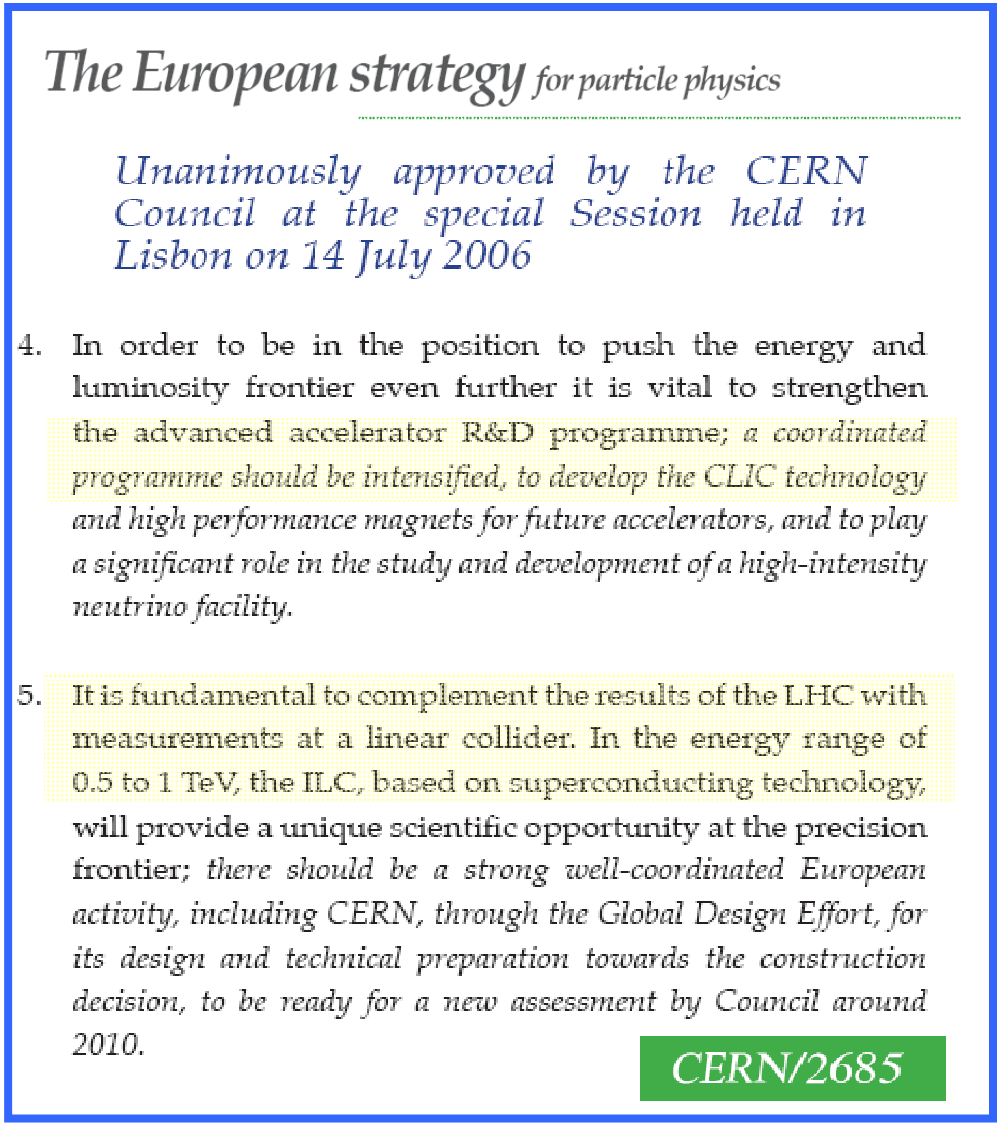
High Energy Physics after LHC


X-BAND RF STRUCTURE
& BEAM DYNAMICS
WORKSHOP
COCKCROFT INSTITUTE
1-4 December 2008

In 1999 ICFA issued a statement on Linear Colliders, ….. that there would be compelling and unique scientific opportunities at a linear electron-positron collider in the TeV energy range. Such a facility is a necessary complement to the LHC hadron collider now under construction at CERN.

Two options: ILC - CLIC

Collaboration on common issues


The European strategy *for particle physics*

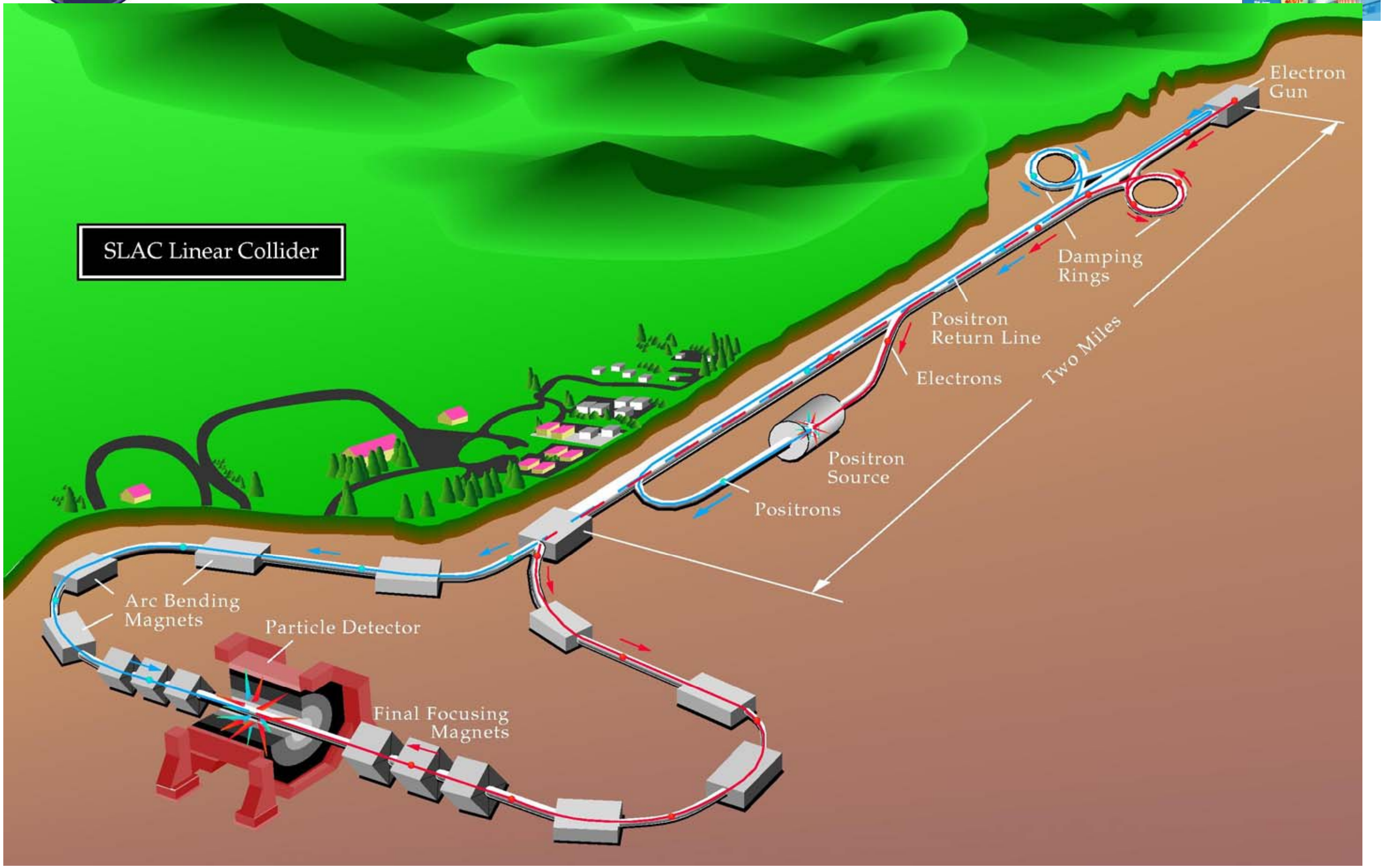
Unanimously approved by the CERN Council at the special Session held in Lisbon on 14 July 2006

4. In order to be in the position to push the energy and luminosity frontier even further it is vital to strengthen the advanced accelerator R&D programme; *a coordinated programme should be intensified, to develop the CLIC technology and high performance magnets for future accelerators, and to play a significant role in the study and development of a high-intensity neutrino facility.*

5. It is fundamental to complement the results of the LHC with measurements at a linear collider. In the energy range of 0.5 to 1 TeV, the ILC, based on superconducting technology, will provide a unique scientific opportunity at the precision frontier; *there should be a strong well-coordinated European activity, including CERN, through the Global Design Effort, for its design and technical preparation towards the construction decision, to be ready for a new assessment by Council around 2010.*

CERN/2685

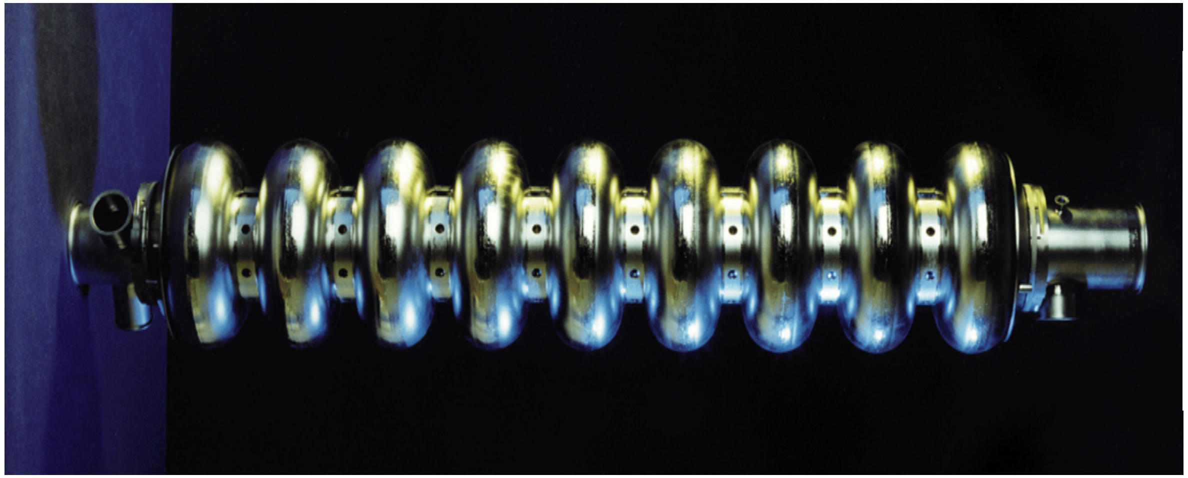
The LC's father: SLC @ SLAC

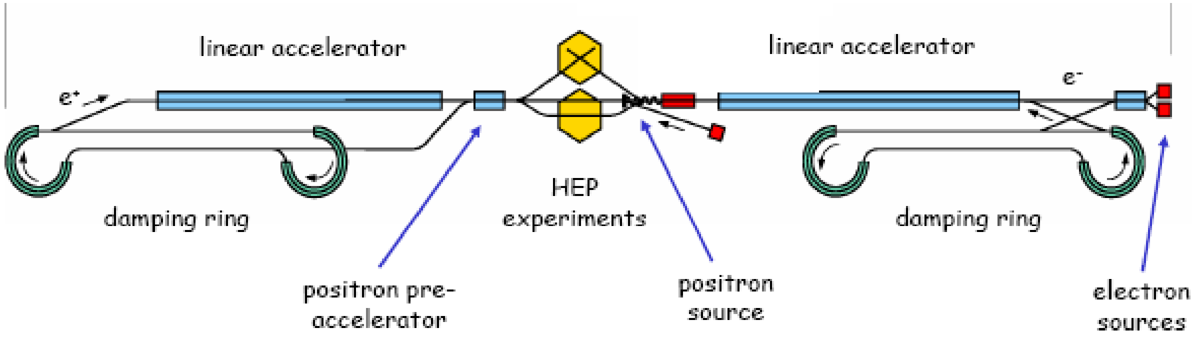


Broad range exploration of technologies (1988 - 2005)

500 GeV	**TESLA**	SBLC	JLC-S	JLC-C	JLC-X	NLC	VLEPP	**CLIC**
Techno.	**Super Conduct**	Norm Cond.	Norm. Cond.	Norm. Cond.	Norm. Cond.	Norm. Cond.	Norm. Cond.	**Two Beams**
f [GHz]	**1.3**	3.0	2.8	5.7	11.4	11.4	14.0	**30.0**
$L \times 10^{33}$ [$cm^{-2}s^{-1}$]	**6**	4	4	9	5	7	9	**1-5**
P_{beam} [MW]	**16.5**	7.3	1.3	4.3	3.2	4.2	2.4	**~1-4**
P_{AC} [MW]	**164**	139	118	209	114	103	57	**100**
$\gamma\varepsilon_y$ [$\times 10^{-8}$m]	**100**	50	4.8	4.8	4.8	5	7.5	**15**
σ_y^* [nm]	**64**	28	3	3	3	3.2	4	**7.4**

Super-conducting technology for TeV Linear Colliders (from TESLA to ILC)





linear accelerator

HEP experiments

linear accelerator

e^+

e^-

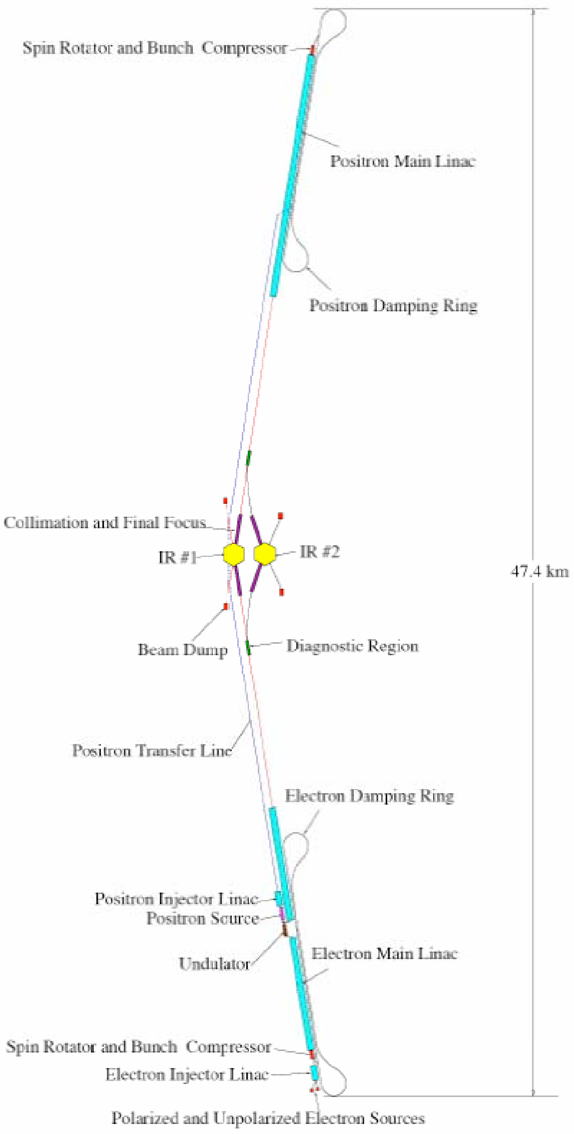
damping ring

damping ring

positron pre-accelerator

positron source

electron sources



Spin Rotator and Bunch Compressor

Positron Main Linac

Positron Damping Ring

Collimation and Final Focus

IR #1

IR #2

47.4 km

Beam Dump

Diagnostic Region

Positron Transfer Line

Electron Damping Ring

Positron Injector Linac

Positron Source

Undulator

Electron Main Linac

Spin Rotator and Bunch Compressor

Electron Injector Linac

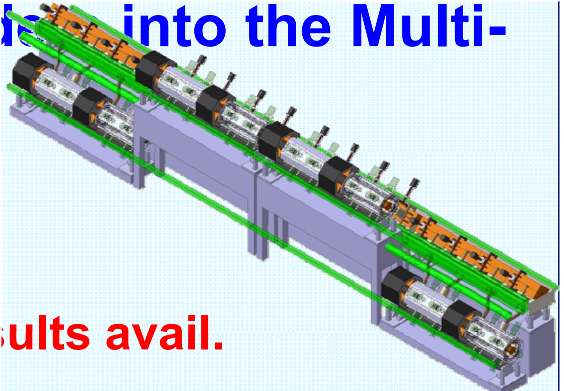
Polarized and Unpolarized Electron Sources

THE COMPACT LINEAR COLLIDER (CLIC) STUDY

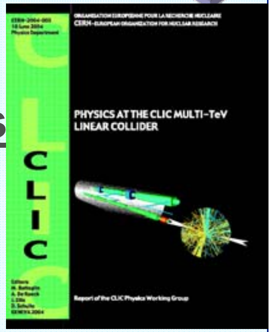

X-BAND RF STRUCTURE & BEAM DYNAMICS WORKSHOP
COCKCROFT INSTITUTE
1-4 December 2008

http://clic-study.web.cern.ch/CLIC-Study/

Site independent feasibility study aiming at the development of a realistic technology to extend e-/e+ linear collid into the Multi-TeV energy range:



- ✓ E_{CM} energy range complementary to LHC
  - => E_{CM} = 0.5- 3 TeV
- ✓ L > few 10^{34} cm^{-2} with acceptable background
  - ⇒ E_{CM} and L to be reviewed when LHC physics results avail.
- ✓ Affordable cost and power consumption


PHYSICS AT THE CLIC MULTI-TeV LINEAR COLLIDER

Physics motivation: http://clicphysics.web.cern.ch/CLICphysics

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

Present goal:

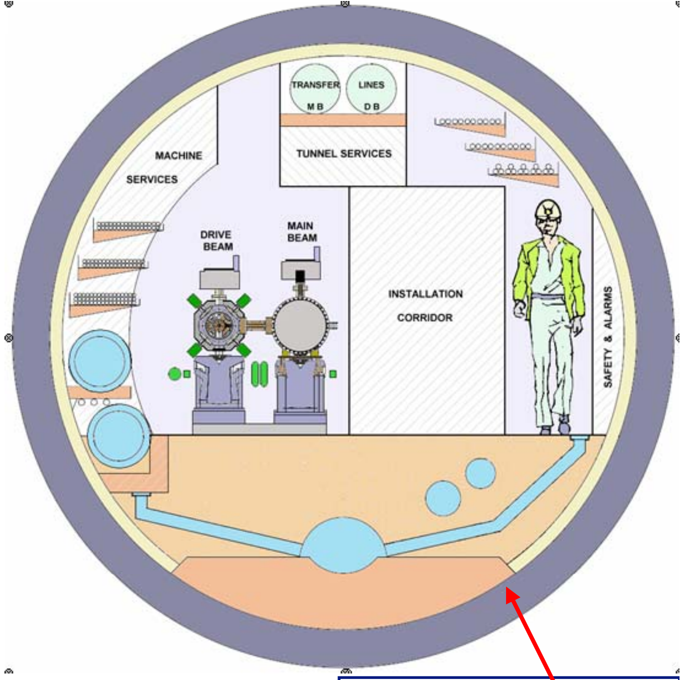
Demonstrate all key feasibility issues and document in a Conceptual Design Report (CDR) by 2010 and possibly Technical Design Report by 2015

CLIC – basic features

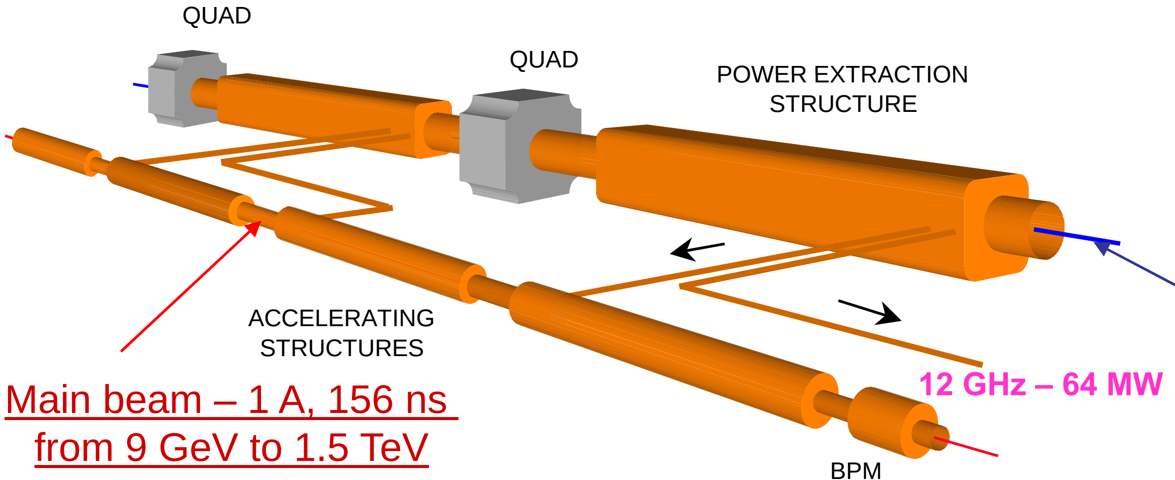
- **High acceleration gradient: > 100 MV/m**
- "Compact" collider – total length < 50 km at 3 TeV
- Normal conducting acceleration structures at high frequency

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

CLIC TUNNEL CROSS-SECTION



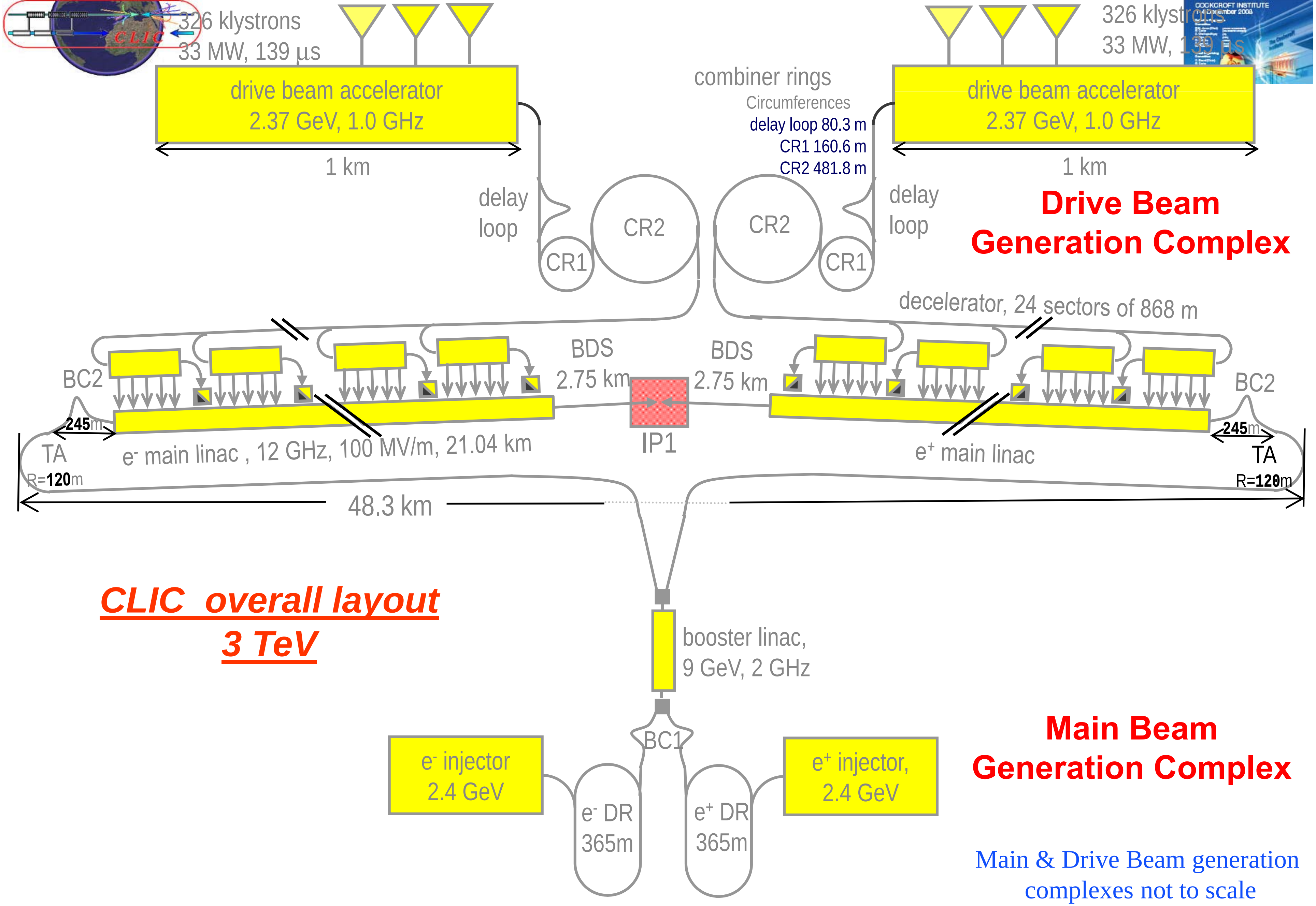
4.5 m diameter



Main beam – 1 A, 156 ns
from 9 GeV to 1.5 TeV
100 MV/m

Drive beam - 95 A, 240 ns
from 2.4 GeV to 240 MeV

CLIC overall layout
3 TeV



326 klystrons
33 MW, 139 μs

drive beam accelerator
2.37 GeV, 1.0 GHz

1 km

delay loop

CR2

CR1

combiner rings
Circumferences
delay loop 80.3 m
CR1 160.6 m
CR2 481.8 m

326 klystrons
33 MW, 139 μs

drive beam accelerator
2.37 GeV, 1.0 GHz

1 km

delay loop

CR2

CR1

Drive Beam Generation Complex

decelerator, 24 sectors of 868 m

BC2

BDS
2.75 km

BDS
2.75 km

BC2

245m

TA
R=120m

e$^-$ main linac , 12 GHz, 100 MV/m, 21.04 km

IP1

e$^+$ main linac

245m

TA
R=120m

48.3 km

booster linac,
9 GeV, 2 GHz

BC1

e$^-$ injector
2.4 GeV

e$^-$ DR
365m

e$^+$ DR
365m

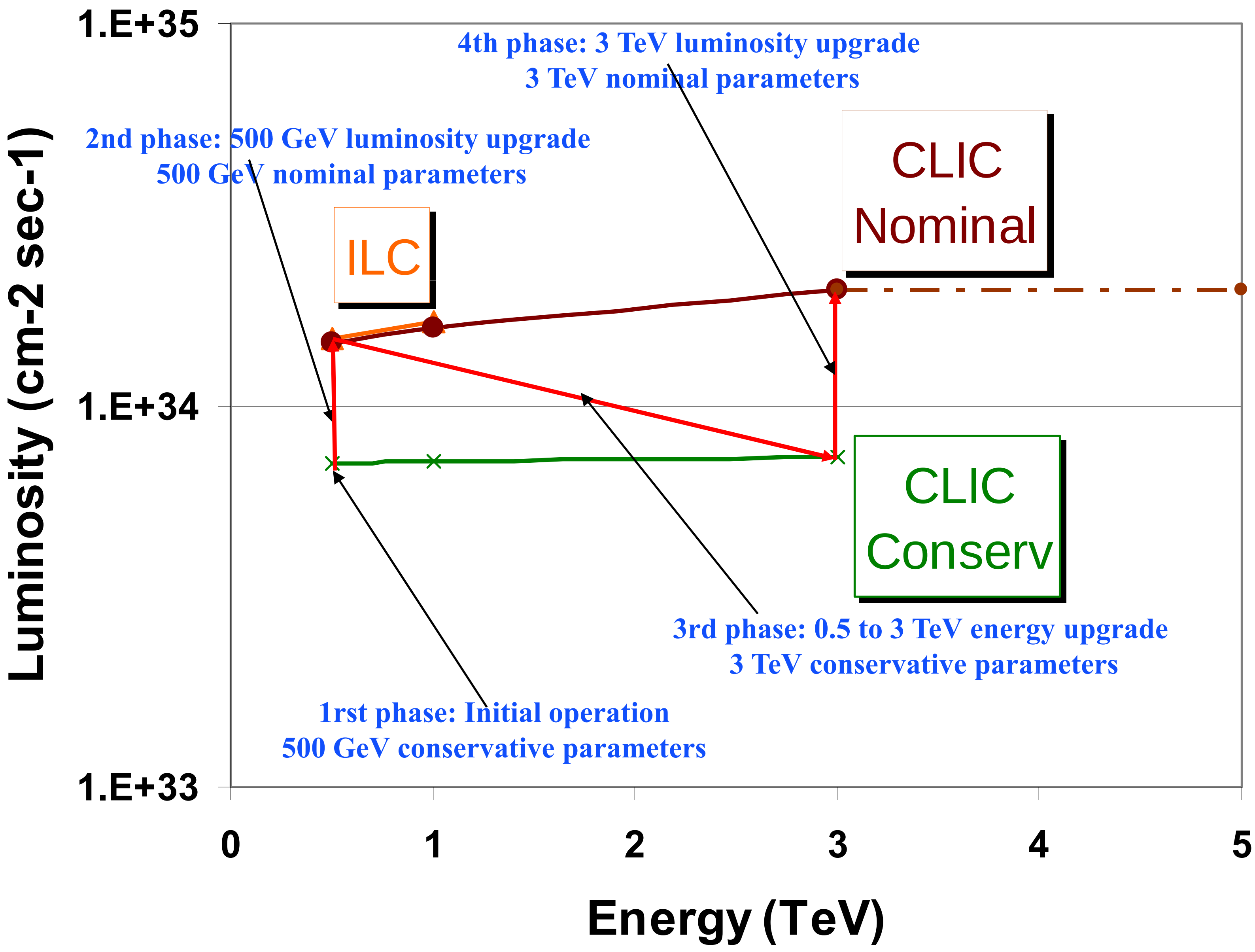
e$^+$ injector,
2.4 GeV

Main Beam Generation Complex

Main & Drive Beam generation complexes not to scale

CLIC Parameters and upgrade scenario

http://clic-meeting.web.cern.ch/clic-meeting/clictable2007.html



4th phase: 3 TeV luminosity upgrade
3 TeV nominal parameters

2nd phase: 500 GeV luminosity upgrade
500 GeV nominal parameters

3rd phase: 0.5 to 3 TeV energy upgrade
3 TeV conservative parameters

1rst phase: Initial operation
500 GeV conservative parameters

J.P.

CLIC main parameters

ttp://cdsweb.cern.ch/record/1132079?ln=fr http://clic-meeting.web.cern.ch/clic-meeting/clictable2007.html

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)·10^{34}	2.3(1.4)·10^{34}	1.5(0.73)·10^{34}	5.9(2.0)·10^{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	8 / 0.3	4 / 0.07
Hor./vert. IP beam size (nm)	248 / 5.7	202 / 2.3	83 / 2.0	40 / 1.0
Hadronic events/crossing at IP	0.07	0.19	0.57	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	

J.

CLIC major activities and milestones up to 2010

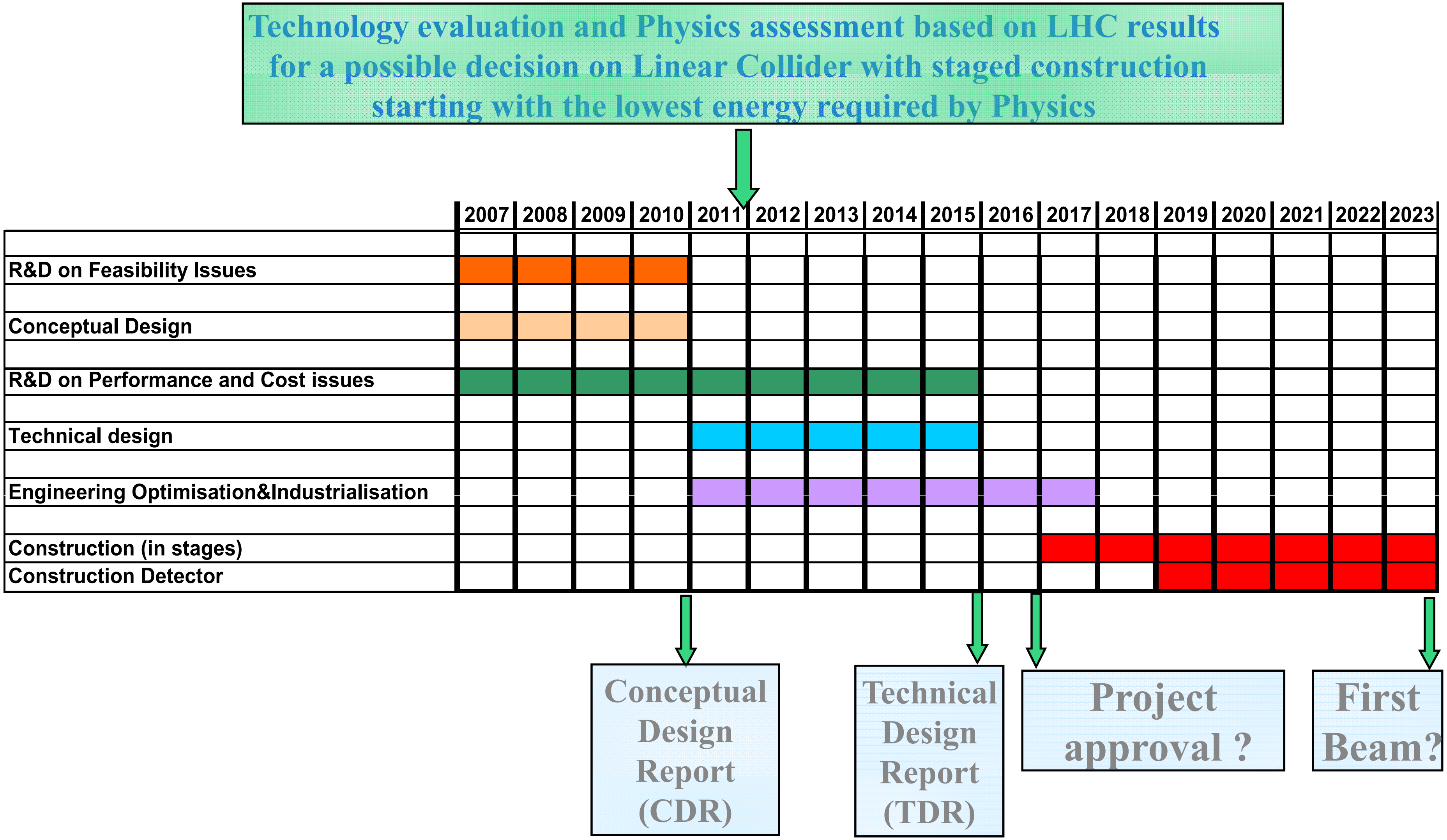
- Demonstrate feasibility of CLIC technology
  - Address all feasibility issues
- Design of a linear Collider based on CLIC technology

  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
  - R&D on critical issues and results of feasibility study,
  - Preliminary performance and cost estimation


X-BAND RF STRUCTURE & BEAM DYNAMICS WORKSHOP
COCKCROFT INSTITUTE
1-4 December 2008

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

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
R&D on Feasibility Issues	🟧	🟧	🟧	🟧													
Conceptual Design	🟧	🟧	🟧	🟧													
R&D on Performance and Cost issues	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩								
Technical design					🟦	🟦	🟦	🟦	🟦								
Engineering Optimisation&Industrialisation					🟪	🟪	🟪	🟪	🟪	🟪	🟪						
Construction (in stages)											🟥	🟥	🟥	🟥	🟥	🟥	🟥
Construction Detector													🟥	🟥	🟥	🟥	🟥

Conceptual Design Report (CDR)

Technical Design Report (TDR)

Project approval ?

First Beam?

CLIC/CTF3 world wide collaboration

Ankara University (Turkey)
Berlin Tech. Univ. (Germany)
BINP (Russia)
CERN
CIEMAT (Spain)
Finnish Industry (Finland)
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)
JASRI (Japan)
JINR (Russia)
JLAB (USA)
KEK (Japan)
LAL/Orsay (France)
LAPP/ESIA (France)
LLBL/LBL (USA)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Oslo University
PSI (Switzerland)
Polytech. University of Catalonia (Spain)
RAL (UK)
RRCAT-Indore (India)
Royal Holloway Univ. London, (UK)
SLAC (USA)
Svedberg Laboratory (Sweden)
Uppsala University (Sweden)

CLIC/CTF3 Collaboration

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

- 27 institutes involving 17 funding agencies from 15 countries
- Organized as a HEP Detector Collaboration
- Started as CTF3, recently extended to CLIC R&D in view of CDR and beyond

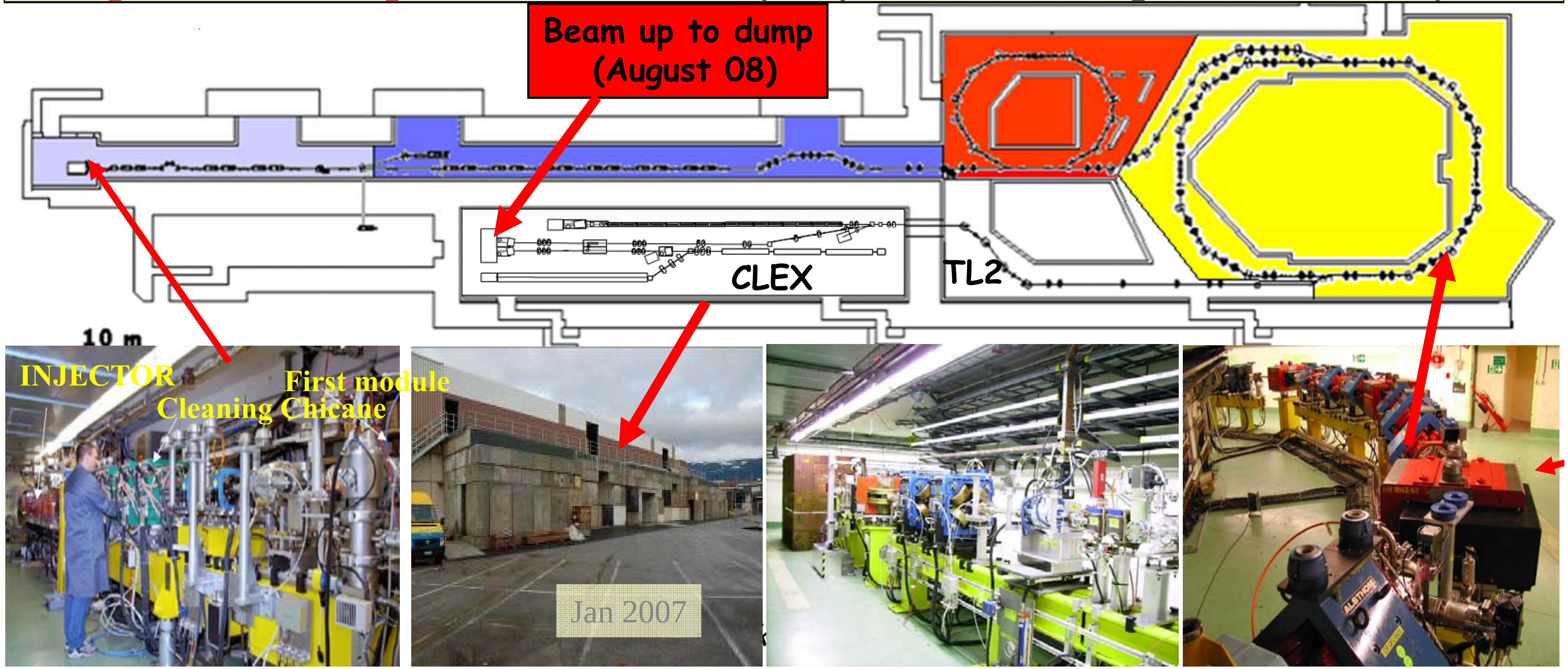
CLIC / ILC Collaboration

http://clic-study.web.cern.ch/CLICStudy/CLIC_ILC_Collab_Mtg/Index.htm

- Focusing on subjects with strong synergy between CLIC & ILC (7 common working groups)
- Making the best use of the available resources
- Identifying and understanding the differences due to technology and energy (technical, cost….)
- Preparing together the future evaluation of the two technologies by the Linear Collider Community made up of CLIC & ILC experts

All major CLIC technology key issues addressed in CLIC Test Facility (CTF3)

- **Demonstrate Drive Beam generation**
  (fully loaded acceleration, beam intensity and bunch frequency multiplication x8)
- **Demonstrate RF Power Production and test Power Structures**
- **Demonstrate Two Beam Acceleration and test Accelerating Structures**
- **Operational Experience (reliability) by continuous operation (10m/year)**

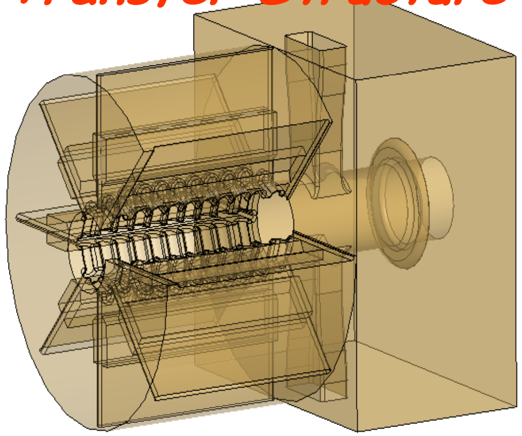

Beam up to dump
(August 08)

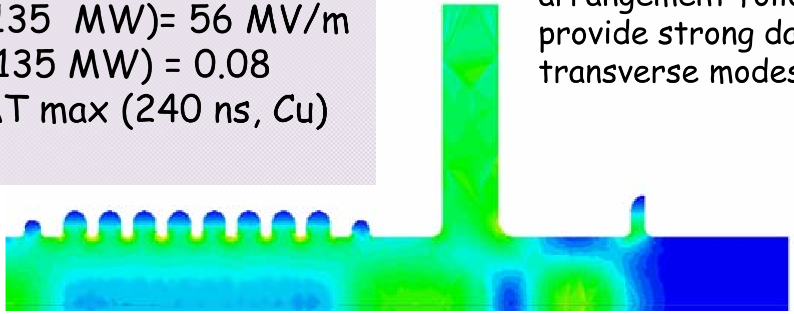
CLIC Power Extraction and Transfer Structure (PETS)

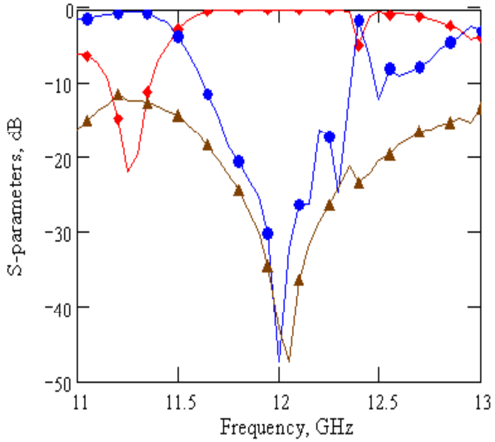
PETS parameters:

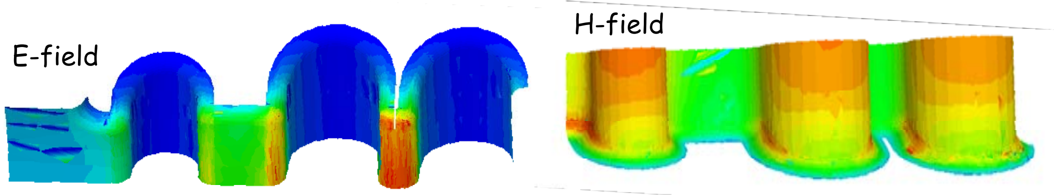
- Aperture = 23 mm
- Period = 6.253 mm (90^0/cell)
- Iris thickness = 2 mm
- R/Q = 2258 Ω
- V group= 0.453
- Q = 7200
- P/C = 13.4
- E surf. (135 MW)= 56 MV/m
- H surf. (135 MW) = 0.08 MA/m (ΔT max (240 ns, Cu) = 1.8 C^0)

In its final configuration, PETS comprises eight octants separated by the damping slots. Each of the slots is equipped with HOM damping loads. This arrangement follows the need to provide strong damping of the transverse modes.



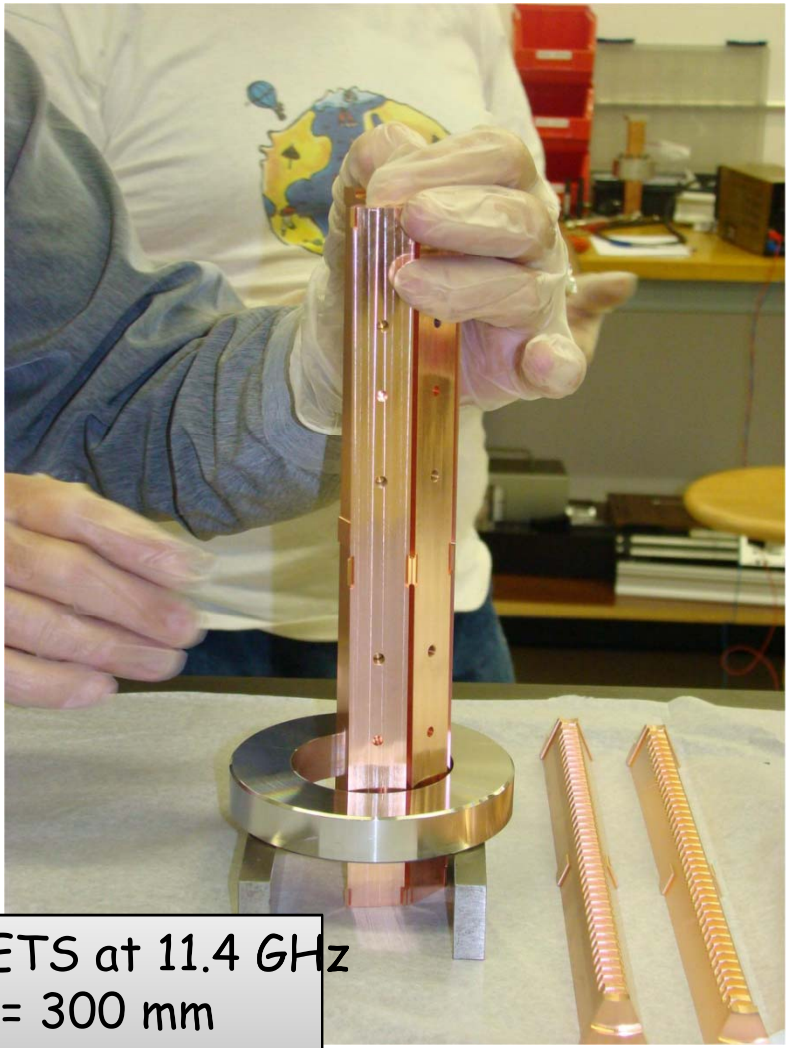




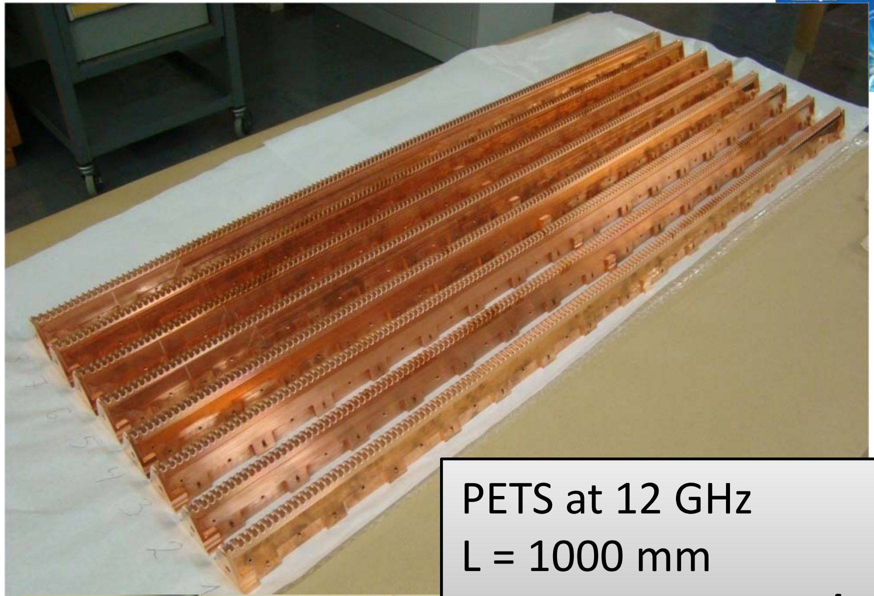


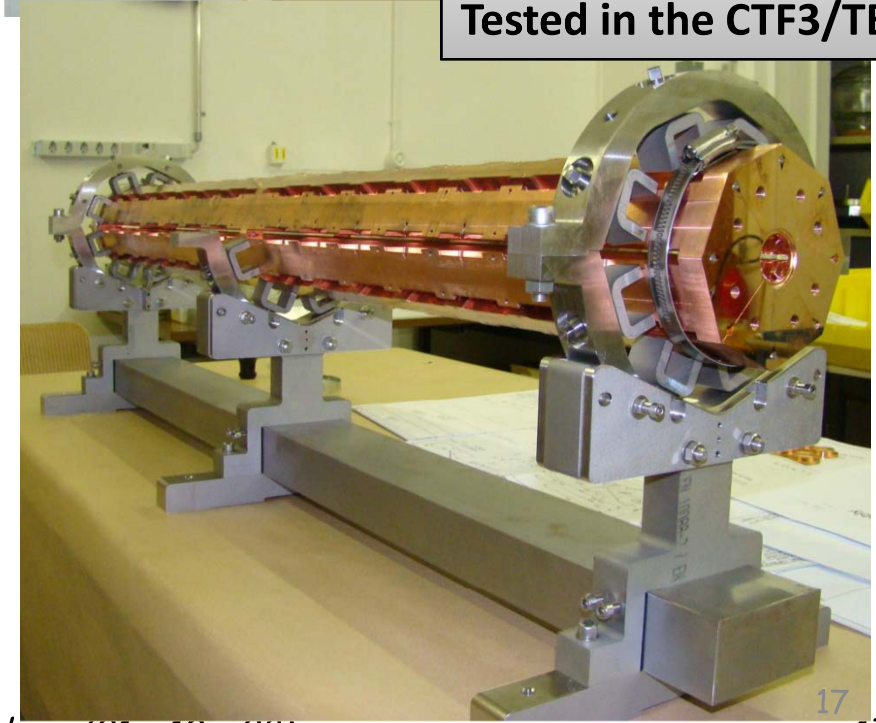
To reduce the surface field concentration in the presence of the damping slot, the special profiling of the iris was adopted.

Power Extraction & Transfer Structure (PETS)



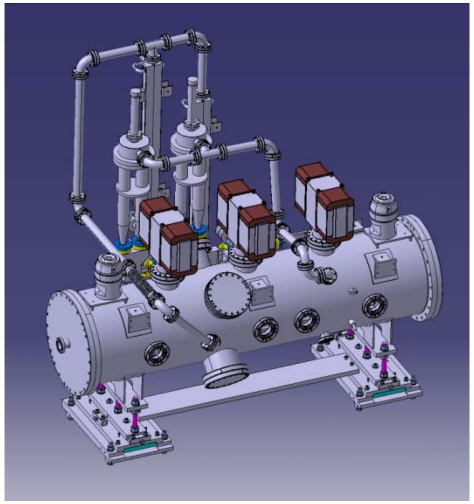
PETS at 11.4 GHz
L = 300 mm
Tested at SLAC

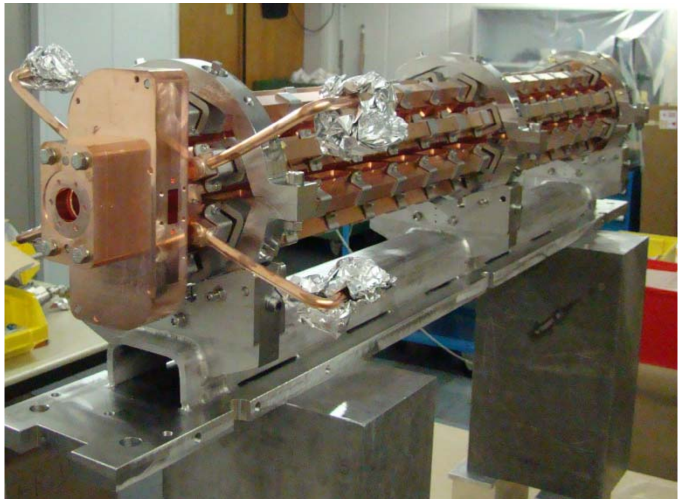




PETS at 12 GHz
L = 1000 mm
Tested in the CTF3/TBTS

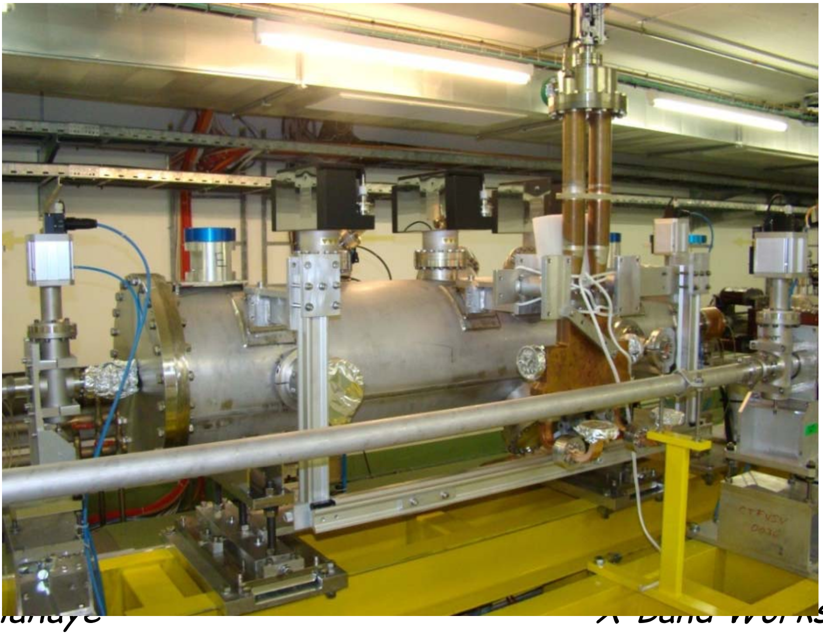
Power Extraction Structure (PETS) Tests in CTF3/CLEX

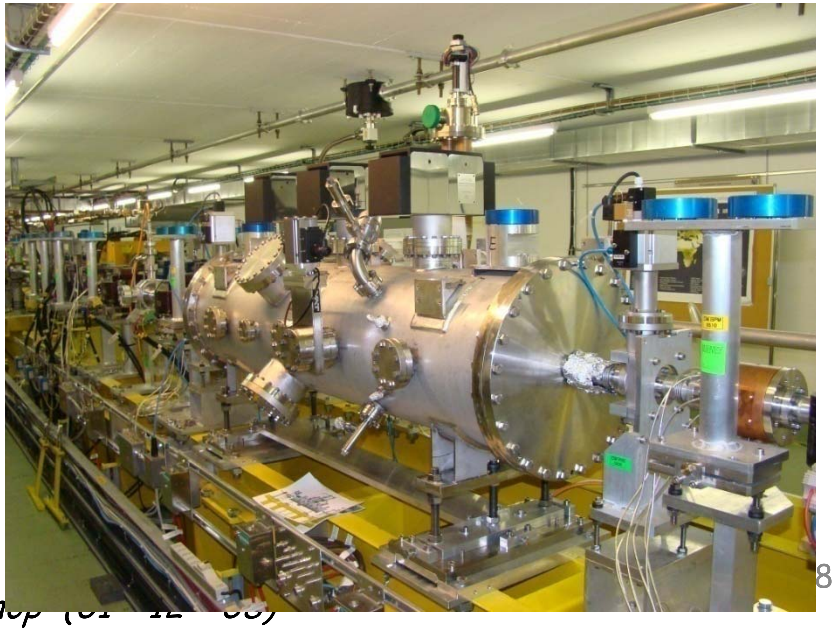




PETS installation in tank successful
(**collaboration with Pakistan – NPC Islamabad**)

PETS installation in CLEX under way

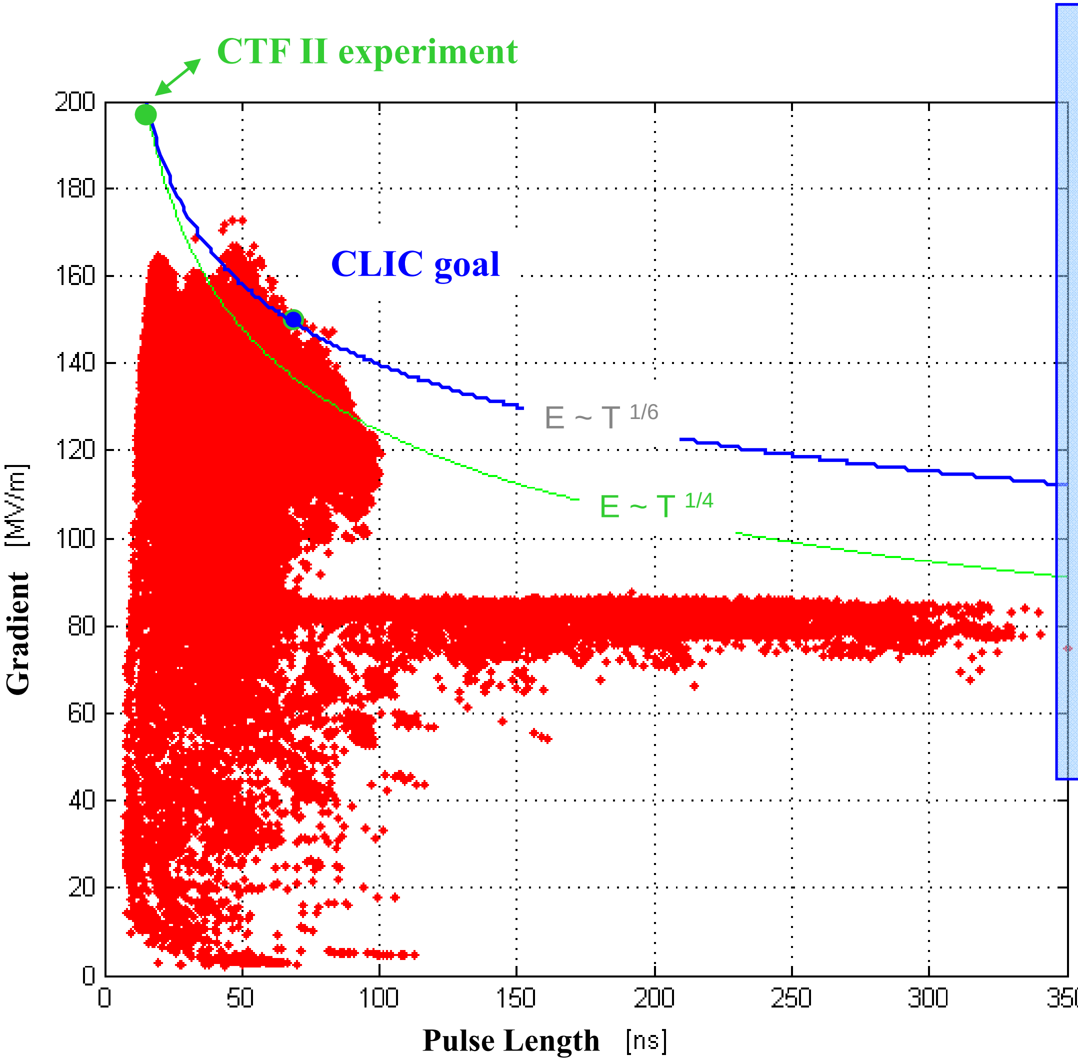




Testing Accelerating Structures

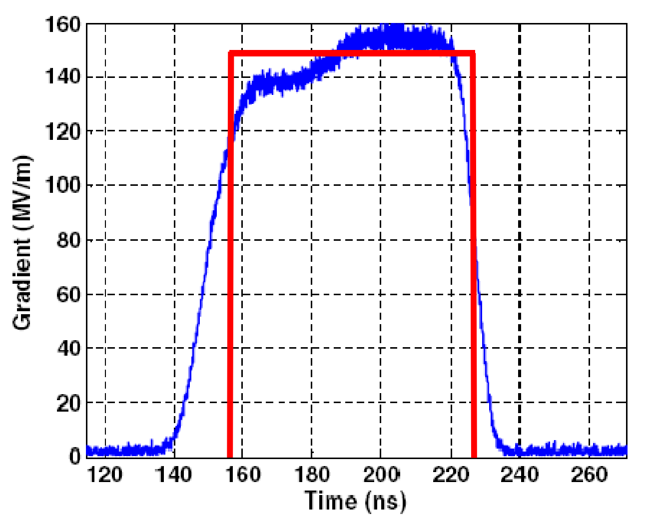
CTF3 High-Power test results @ 30 GHz

-



Reached nominal CLIC values :

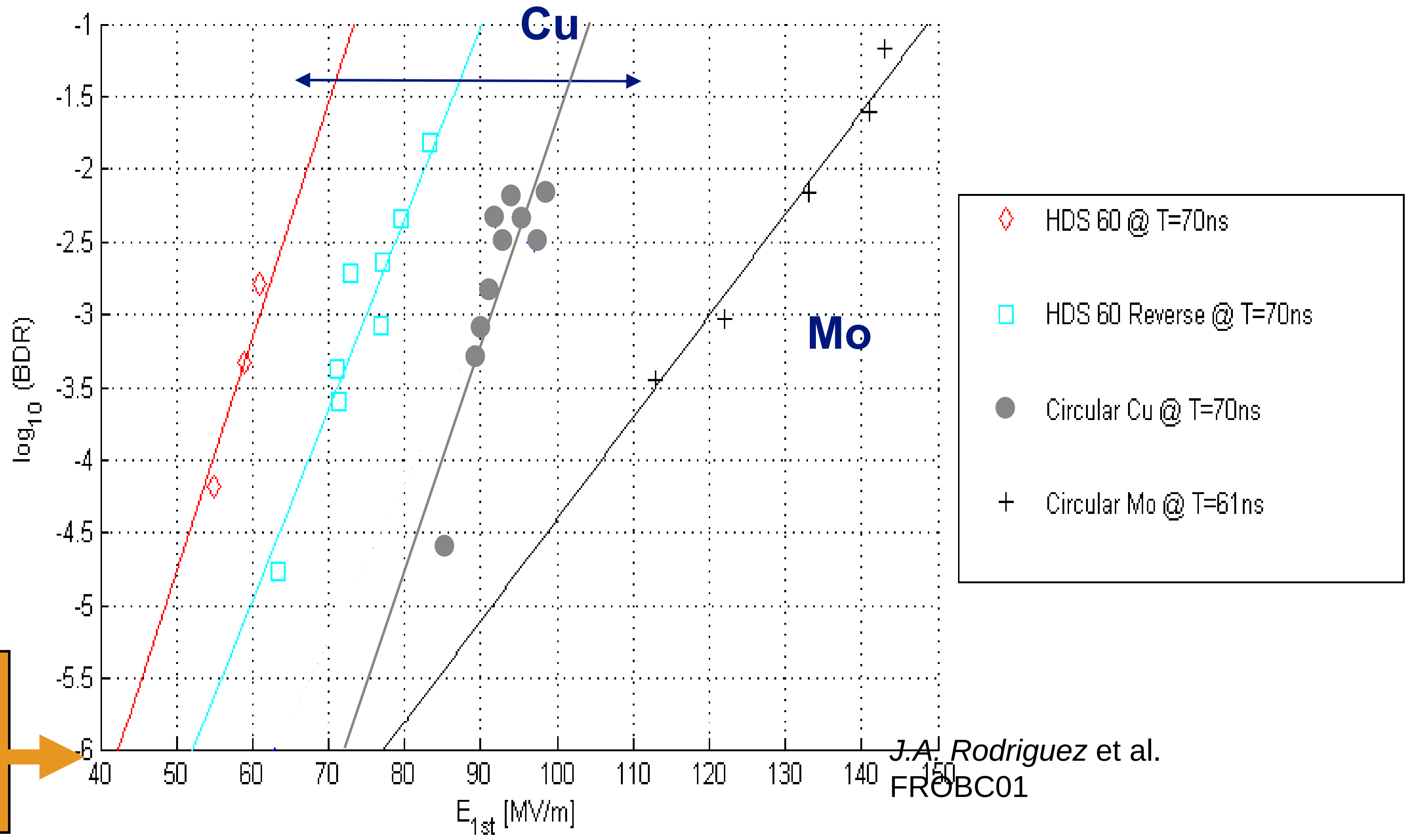
150 MV/m - 70 ns



Breakdown Rate not compatible with LC operation

CTF3 High-Power tests various materials @ 30 GHz

- Acceptable Breakdown Rate in linear collider operation not higher than 10-6
- Reduction of accelerating field by about 30 MV/m for low BR with Cu



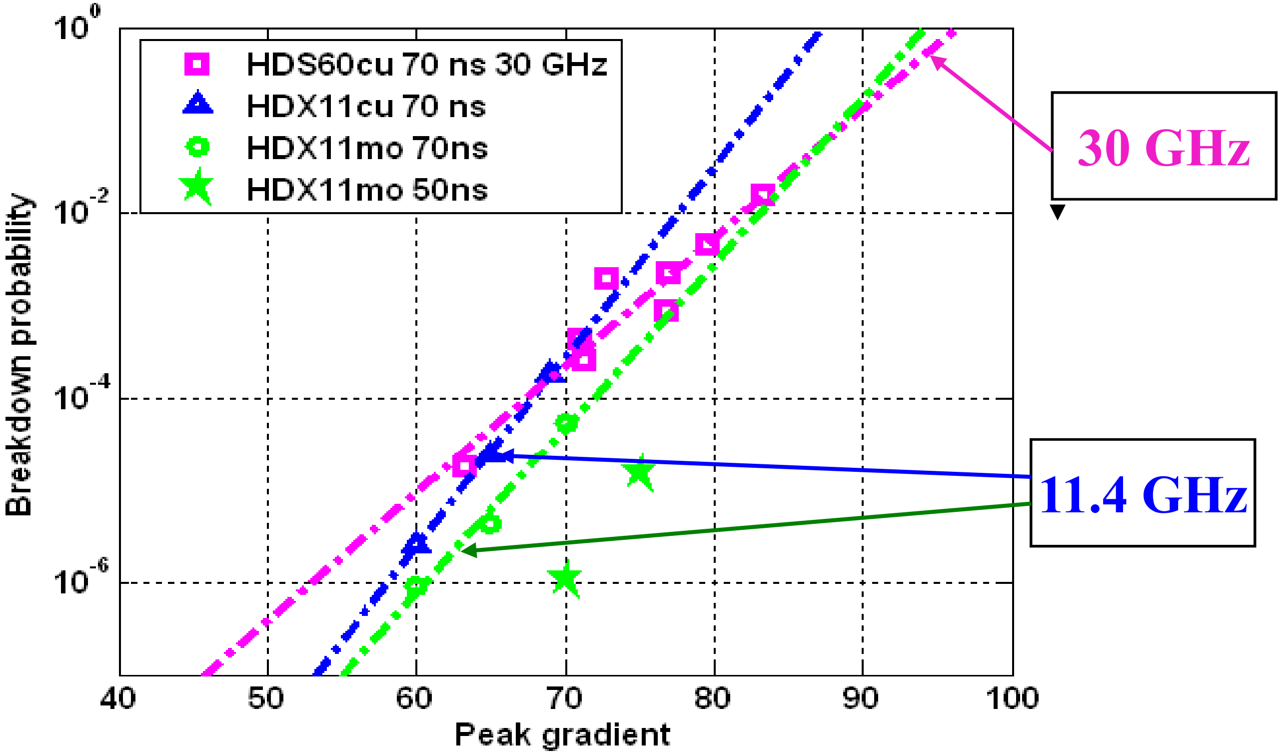
CLIC operational goal

J.A. Rodriguez et al.
FROBC01

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

- Structures with scaled geometries at different frequencies have same performance

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



CLIC overall optimisation model

Accelerating structure limitations:

rf breakdown and pulsed surface heating (rf) constraints:

Beam dynamics constraints:

Beam quality preservation during acceleration in main linac with high wake fields environment: (conditions similar to NLC)

Beam focusing in Beam Delivery System and collison in detector in high beamstrahlung regime

Deduce CLIC parameters and performance: > 200 millions structures

Optimising

Performance or figure of merit

Luminosity per linac input power:

$$\int L dt / \int P dt \sim L_{b\times}/N\eta$$

Cost estimation of the overall complex at 3 TeV (invest. & exploit. 10 years)

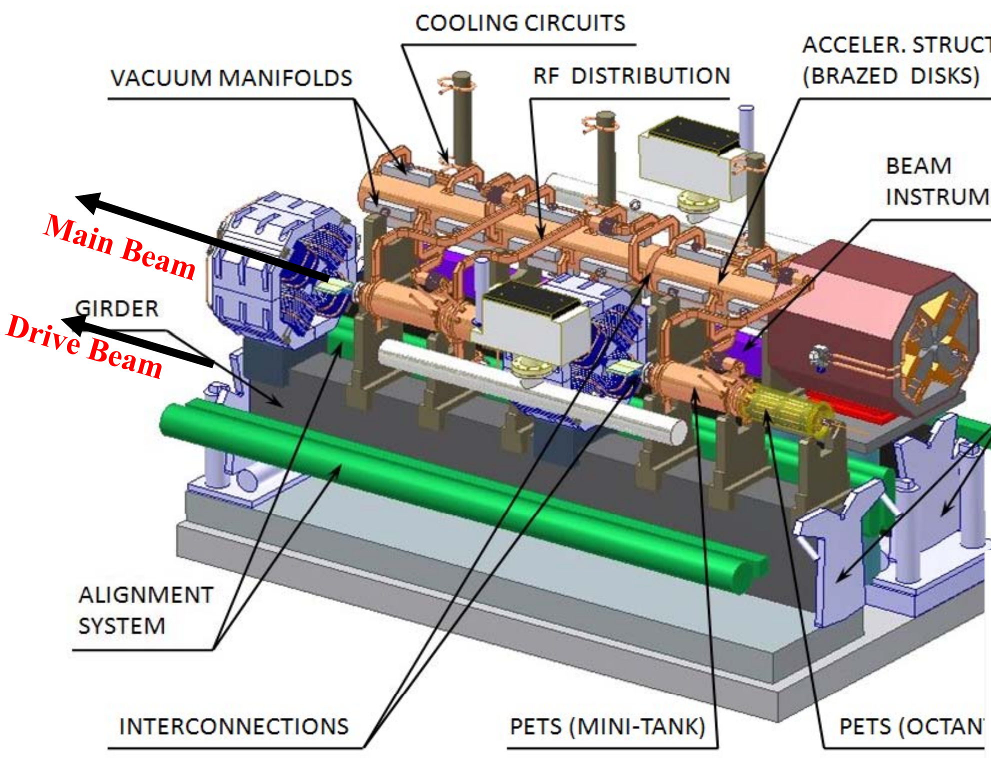
Cost estimation and cost model

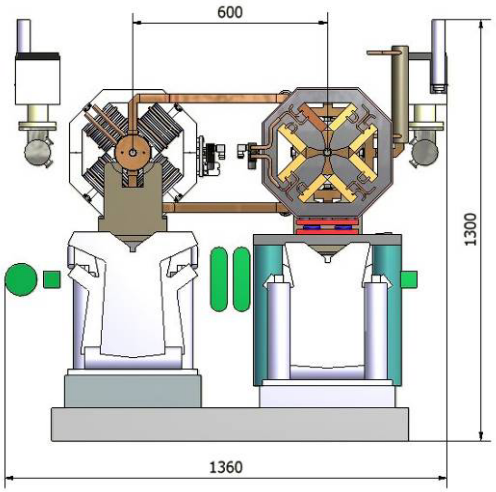
Work in progress aiming for reliable cost estimate by 2010

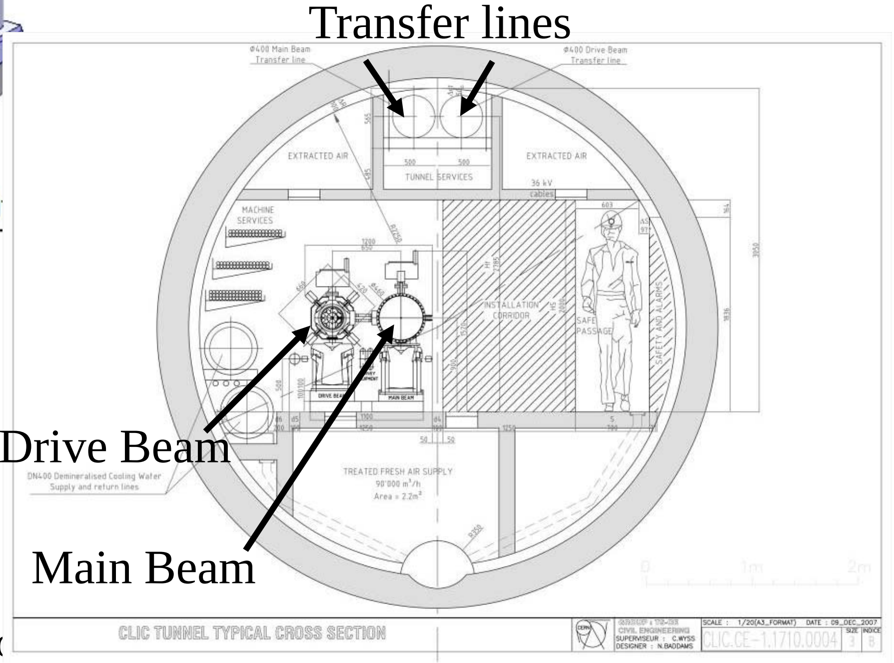
  - Presently still large imprecision

- Define cost drivers for Cost Conscious Design guiding
- Cost estimation in parallel with the ILC cost estimate for better comparison of the two technologies,
  - in collaboration with ILC experts,
  - by the same persons,
  - using the same tools,
  - on the same site as for the ILC@CERN
- Parametric model to estimate the influence on cost of the variation parameters
  - Design guiding
  - Cost scaling with colliding beam energy

CLIC Two Beam Module







20760 modules (2 meters long)

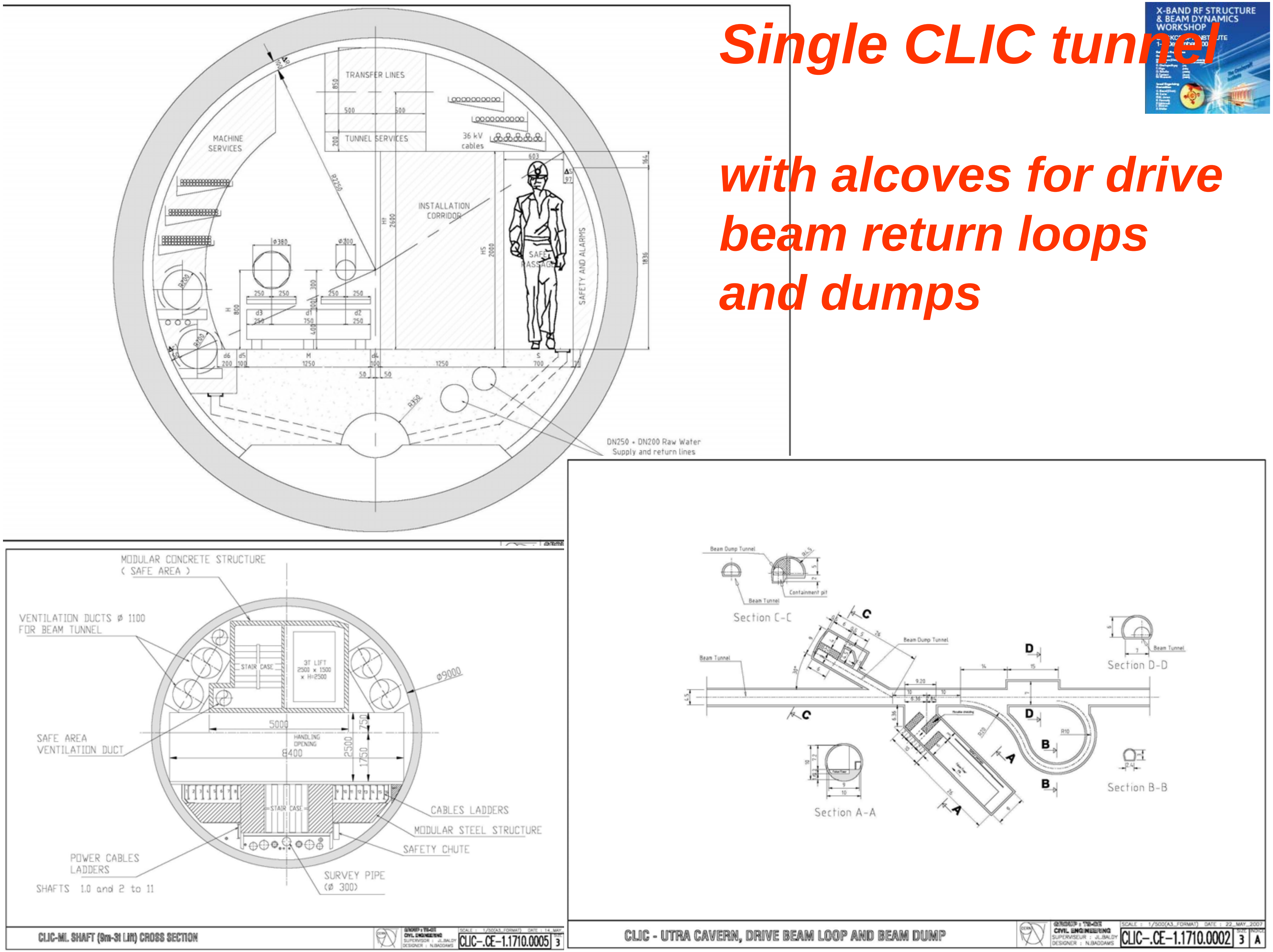
71460 power production structures PETS (drive beam)

143010 accelerating structures

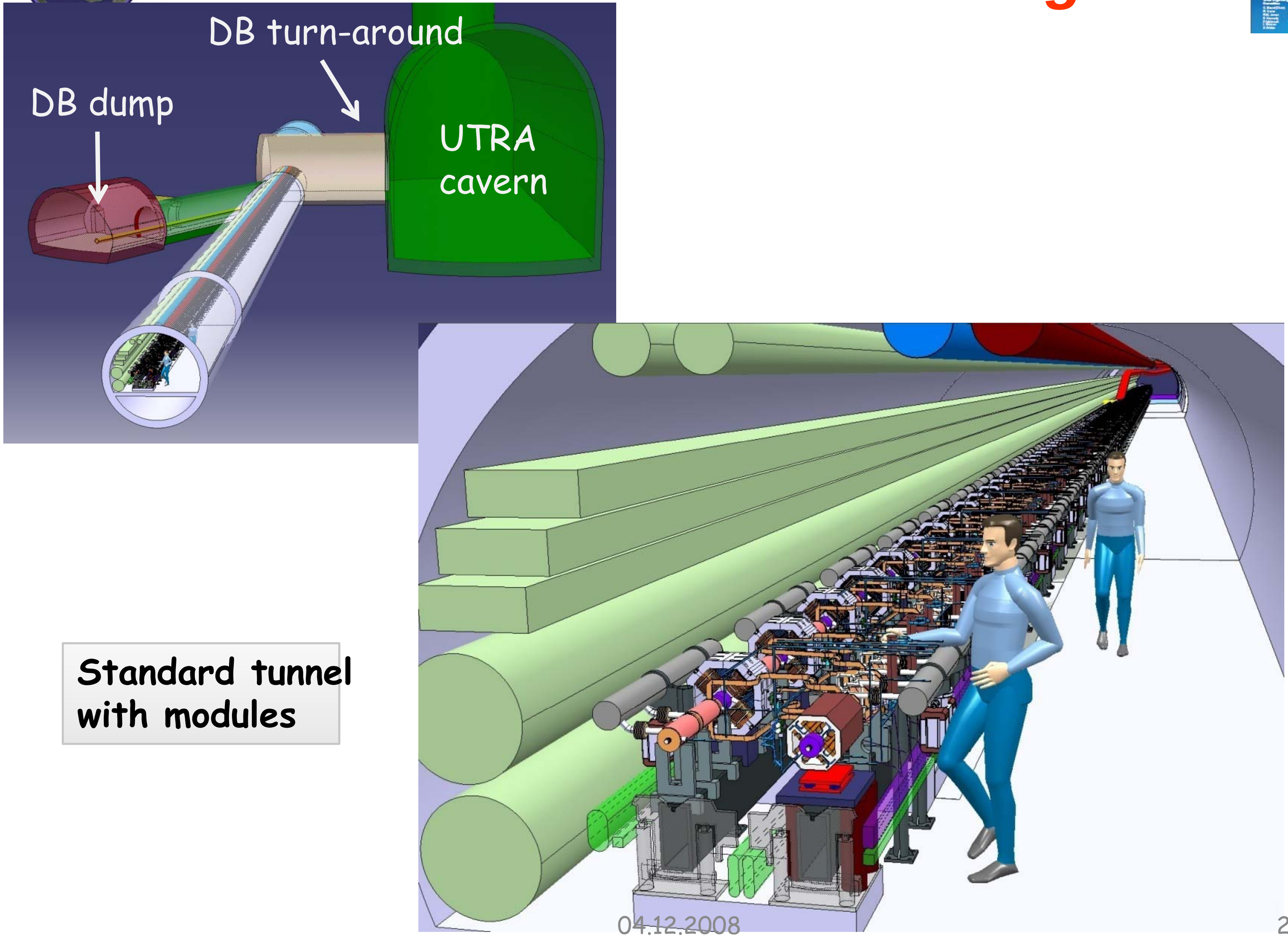
(main beam)

Single CLIC tunnel

with alcoves for drive beam return loops and dumps

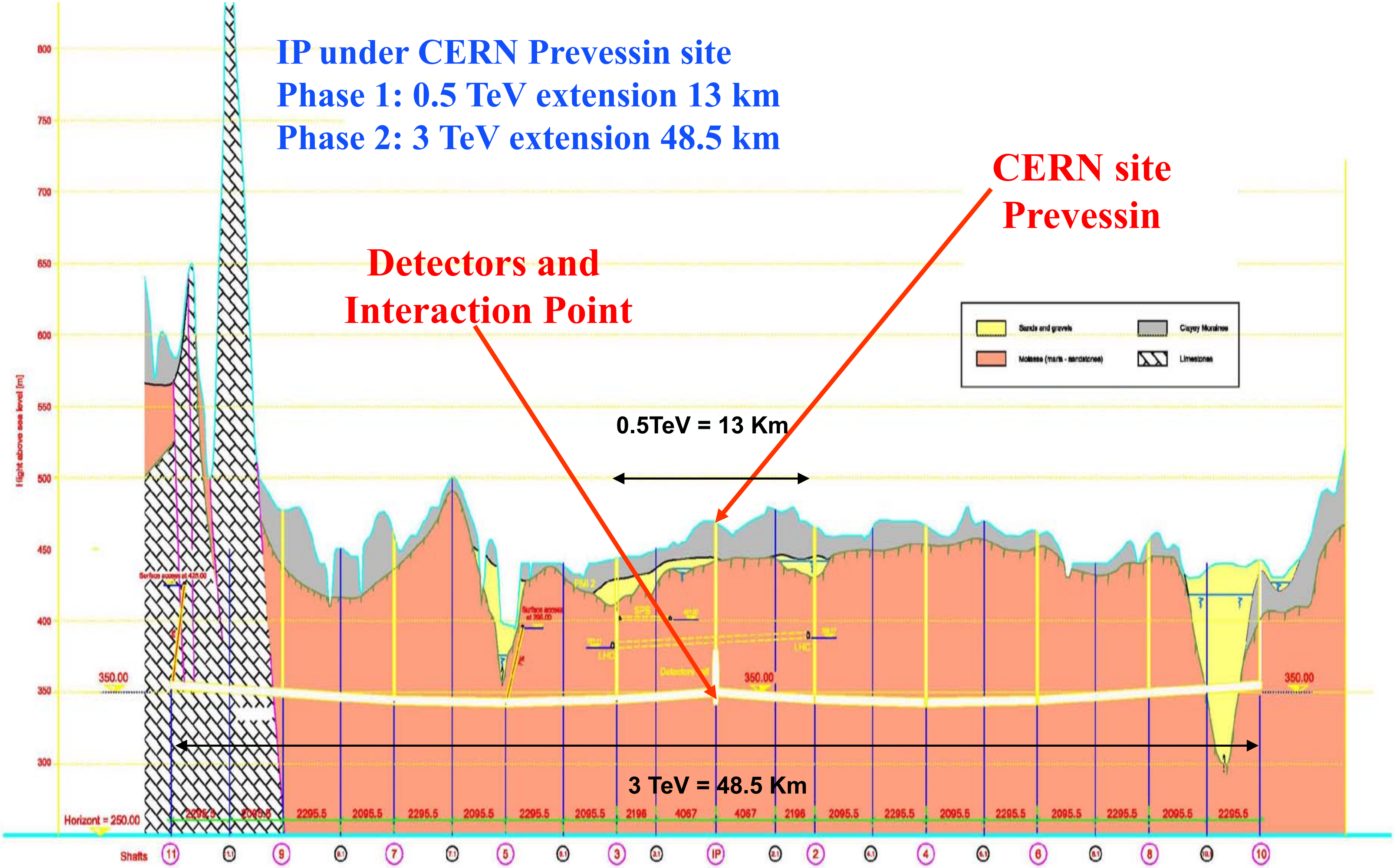


Tunnel integration



Standard tunnel with modules

Longitudinal section of a laser straight Linear Collider on CERN site–



IP under CERN Prevessin site
Phase 1: 0.5 TeV extension 13 km
Phase 2: 3 TeV extension 48.5 km

CERN site Prevessin

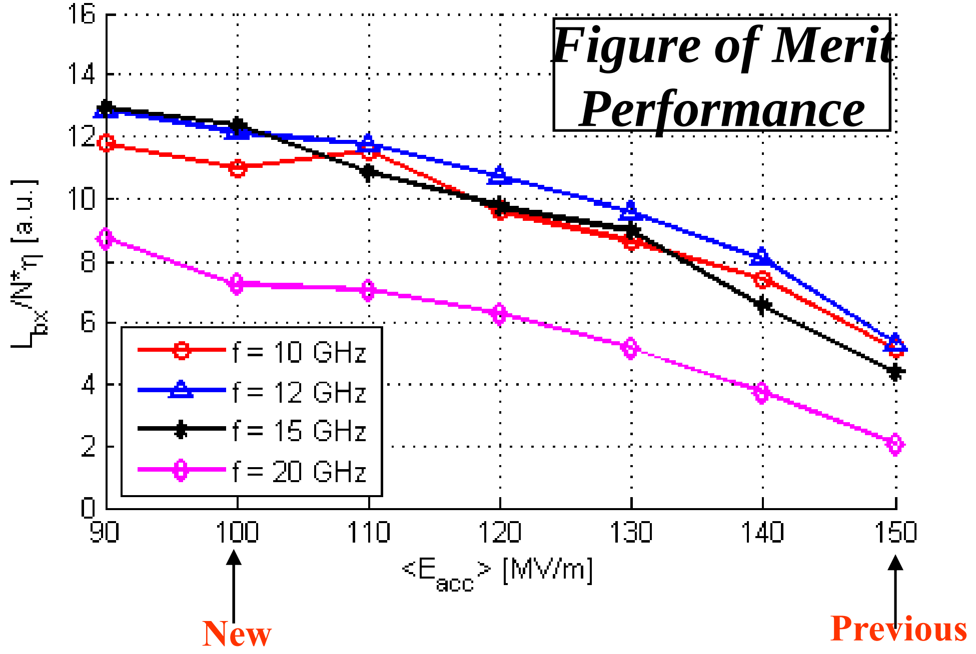
Detectors and Interaction Point

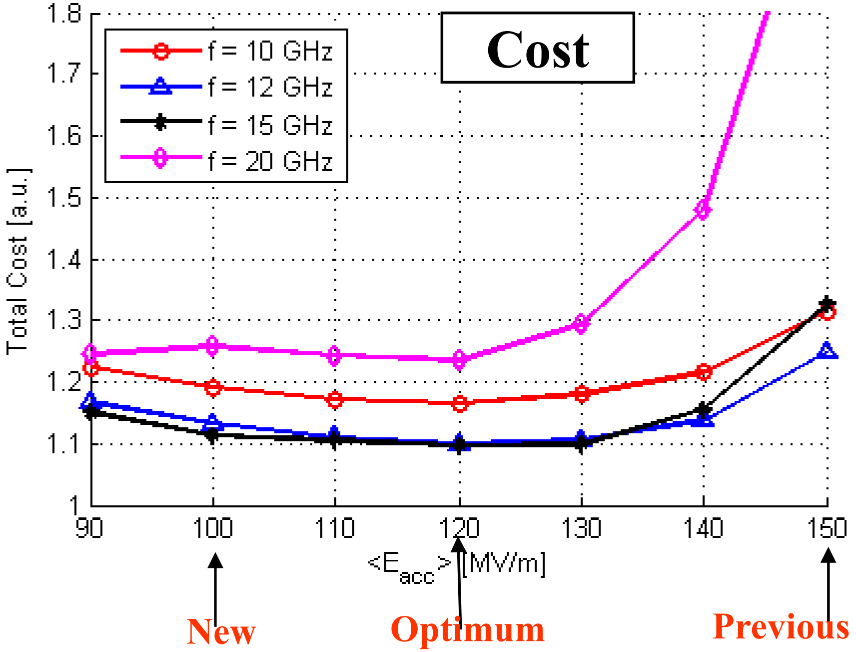
0.5TeV = 13 Km

3 TeV = 48.5 Km

CLIC performances (FoM) and cost (relative) versus accelerating gradient

E_{cms} = 3 TeV $L_{(1\%)}$ = 2.0 10^{34} $cm^{-2}s^{-1}$

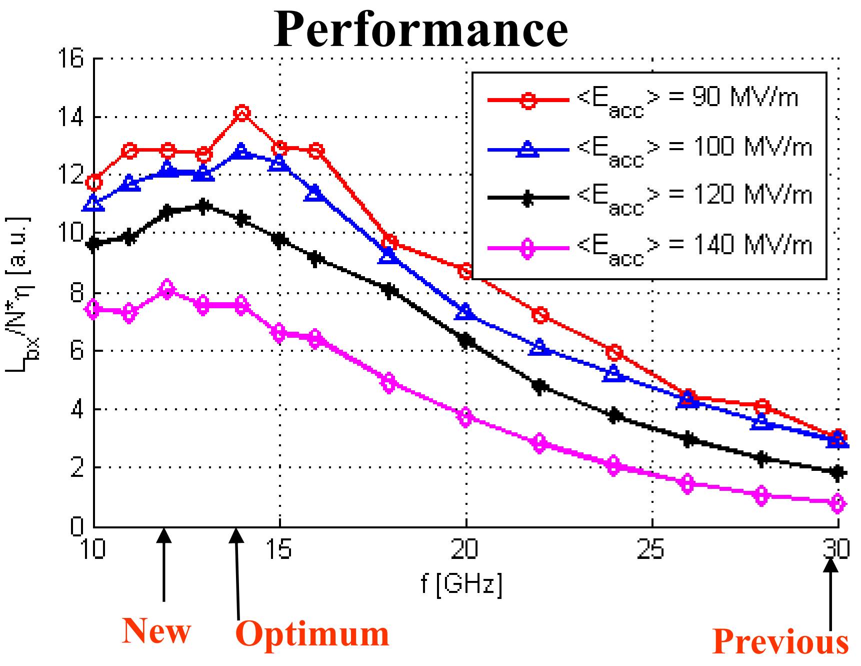




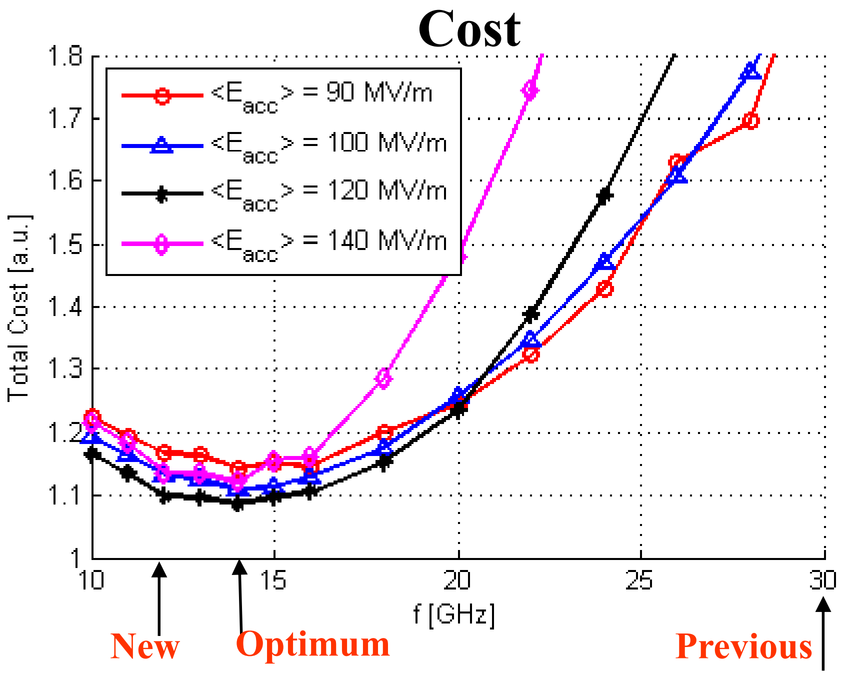
- **Performances increasing with lower accelerating gradient (mainly due to higher efficiency)**
- **Flat cost variation in 100 to 130 MV/m with a minimum around 120 MV/m**

CLIC performances (FoM) and cost optimisation as function of RF frequency

E_{cms} = 3 TeV $L_{(1\%)}$ = 2.0 10^{34} $cm^{-2}s^{-1}$



Performance



Cost

- **Maximum Performance around 14 GHz**
- **Flat cost variation in 12 to 16 GHz frequency range with a minimum around 14 GHz**

The Beauty of X band (12 GHz)

- Close to maximum Performance and minimum Cost (14 GHz)
- Very close to the NLC and JLC frequency: 11.4 GHz
  - Building up on wide expertise and long-term R&D made during many years on warm structures, RF power sources, beam dynamics at SLAC and KEK
  - **Take advantage of low(er than 30 GHz) frequency for easier fabrication (tolerances, vacuum), relaxed requirements (alignment, timing, etc…),**
- RF power generation and frequency multiplication in CLIC TBA RF Power Source
  - **Possibly drive beam linac at 1.3 GHz (with possible synergy with ILC MBK developments) and multiplication by 8 (2*4) instead 36**
  - **High gradients achievable with short RF pulse provided by TBA RF power source**
  - **Easy adaptation of CTF3 (multiplication factor by 8 instead of 10)**
- Stand alone power sources available:
  - **Makes the best use of developments and equipments at SLAC and KEK**

Fruitful collaboration with U.S. Collaboration on High Gradient Research

- **Purpose:**

  The purpose of this collaboration is to perform research to determine the gradient potential of normal-conducting, RF-powered particle beam accelerators, and to develop the necessary accelerator technology to achieve those high gradients. Harnessing the momentum of the concluded NLC/JLC development programs and working in conjunction with the ongoing CLIC studies, the collaboration will explore the possibility of pushing the useable acceleration gradient from the 65 MV/m reliably achieved for NLC up towards 180 MV/m or higher. Advancing the state-of-the-art in this area is essential to the realization of a post-ILC, multi-TeV linear collider using two-beam RF power generation.

  This research and development effort will include studying the RF breakdown phenomenon itself, theoretically and experimentally. It will aim to establish a better understanding of the frequency scaling of the limiting gradient, as well as its dependence on material, surface preparation, structure design, *etc.* It will explore the high gradient barriers due to choices made in linear collider programs to date. The experimental side of this effort will entail the upgrade of test facilities and the development of new high-power RF sources specifically designed for high gradient testing. The final goal is to produce and successfully test at very high gradient an accelerator structure suitable for use in a multi-TeV two-beam linear collider.

- **Started July 2005 with DOE funds**

Members of U.S. Collaboration on High Gradient Research

- US National Labs:

  ANL, LBNL, NRL, SLAC
- Universities:

  University of Maryland, MIT, University Colorado
- Business Associates:

  Omega-P, Inc., Calabazas Creek Research, Inc., Haimson Research Corporation, Tech-X Corporation, Communications and Power Industries
- Foreign Collaboration:

  CERN, KEK

Spokesperson: S.Tantawi/SLAC

Governance with CERN participation (E.Jensen)

Scope of the US High Gradient Research

- **Frequency scaling:**

  CERN and SLAC experiments have shown less frequency dependence than expected; however, frequency links other parameters such as pulse length, filling time, power, energy, and geometry.

- **Geometry dependence:**

  There is a clear geometry dependence; e.g., accelerator structures with different a/λ, and circuit dependence; e.g., standing wave. vs. traveling wave; however, the origin of this dependence is not clear.

- **Energy, power and pulse length:**

  There is a clear pulse length dependence; however, the laws that govern it are debatable and differ from one experimental set up to another.

- **Materials:**

  Very little is known about materials and D.C. data does not seem to apply. There may be opportunities for significant developments here.

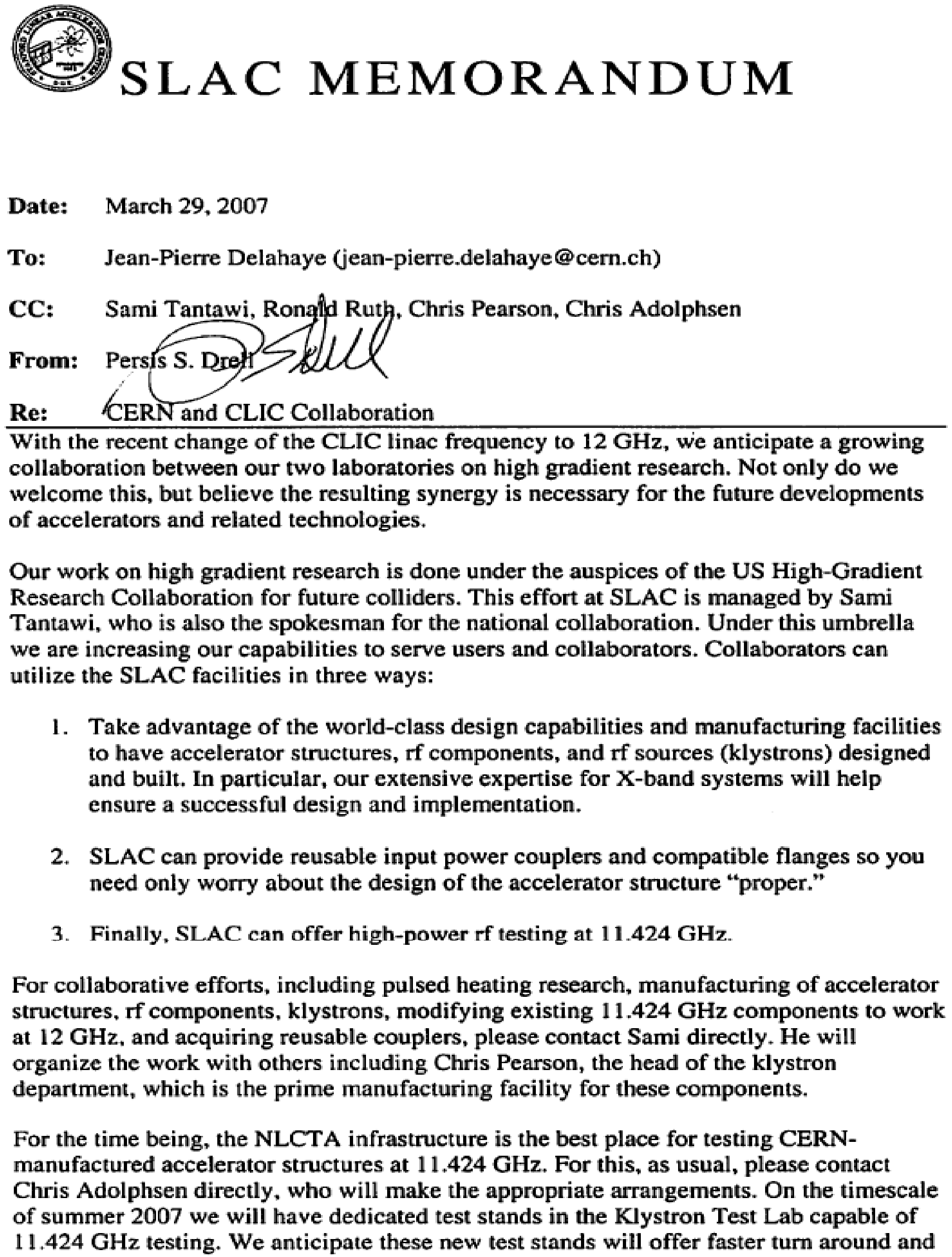
- **Surface processing technique (etching, baking, etc.):**

  There are known practices that have been proven to help; however, the basic physics are still under debate, and the question of processing vs. initial condition of the surface is in question.

- **Theory:**

  There is no robust theory to date, although several attempts at particle tracking, scaling with surface physics, and surface atoms dynamics have been put forward.

Collaboration with SLAC



SLAC MEMORANDUM

Date: March 29, 2007

To: Jean-Pierre Delahaye (jean-pierre.delahaye@cern.ch)

CC: Sami Tantawi, Ronald Ruth, Chris Pearson, Chris Adolphsen

From: Persis S. Drell

Re: CERN and CLIC Collaboration

With the recent change of the CLIC linac frequency to 12 GHz, we anticipate a growing collaboration between our two laboratories on high gradient research. Not only do we welcome this, but believe the resulting synergy is necessary for the future developments of accelerators and related technologies.

Our work on high gradient research is done under the auspices of the US High-Gradient Research Collaboration for future colliders. This effort at SLAC is managed by Sami Tantawi, who is also the spokesman for the national collaboration. Under this umbrella we are increasing our capabilities to serve users and collaborators. Collaborators can utilize the SLAC facilities in three ways:

1. Take advantage of the world-class design capabilities and manufacturing facilities to have accelerator structures, rf components, and rf sources (klystrons) designed and built. In particular, our extensive expertise for X-band systems will help ensure a successful design and implementation.

2. SLAC can provide reusable input power couplers and compatible flanges so you need only worry about the design of the accelerator structure "proper."

3. Finally, SLAC can offer high-power rf testing at 11.424 GHz.

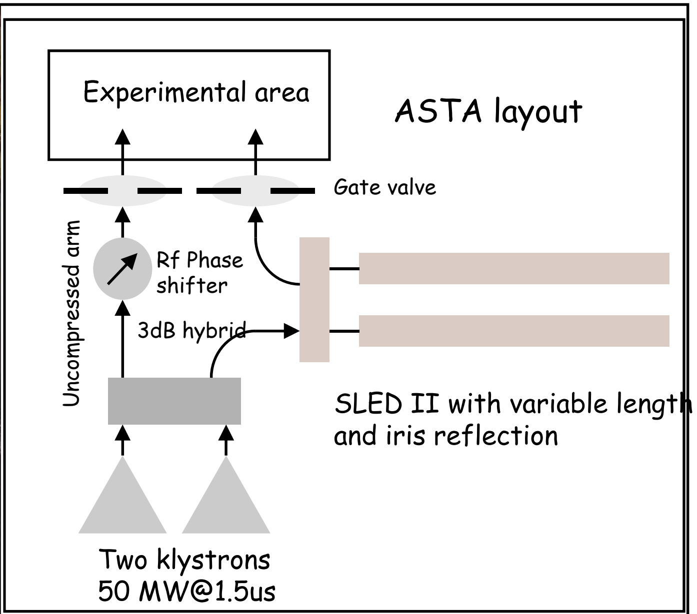
For collaborative efforts, including pulsed heating research, manufacturing of accelerator structures, rf components, klystrons, modifying existing 11.424 GHz components to work at 12 GHz, and acquiring reusable couplers, please contact Sami directly. He will organize the work with others including Chris Pearson, the head of the klystron department, which is the prime manufacturing facility for these components.

For the time being, the NLCTA infrastructure is the best place for testing CERN-manufactured accelerator structures at 11.424 GHz. For this, as usual, please contact Chris Adolphsen directly, who will make the appropriate arrangements. On the timescale of summer 2007 we will have dedicated test stands in the Klystron Test Lab capable of 11.424 GHz testing. We anticipate these new test stands will offer faster turn around and

Accelerating Structure Test Areas at SLAC in Klystron Lab and NLC-TA

The ASTA pulse compressor with variable delay in delay-lines

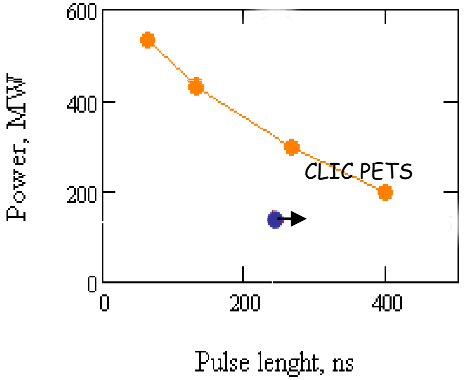
The ASTA pulse compressor with variable iris

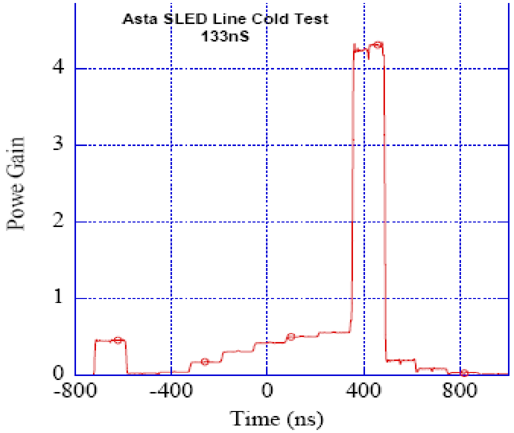


The uncompressed arm has a variable phase shifter and a gate valve

ASTA is a new generation general purpose test stand, which will allow processing the various types of the high power RF equipment at X-band. The facility can provide a very versatile pulse length and power level.

RF pulse @ power in the ASTA compressed arm



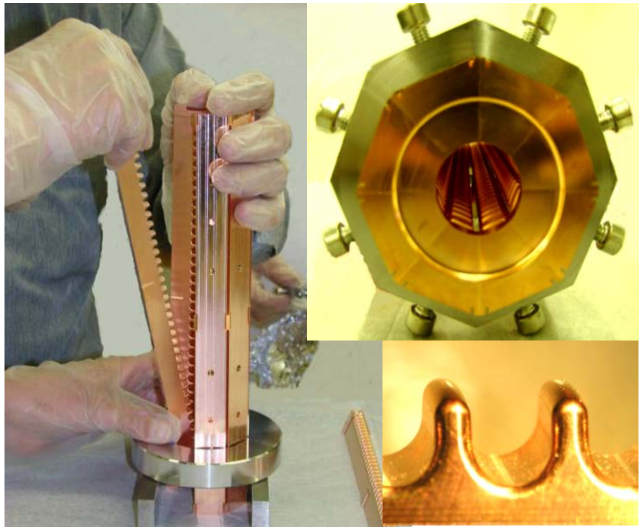


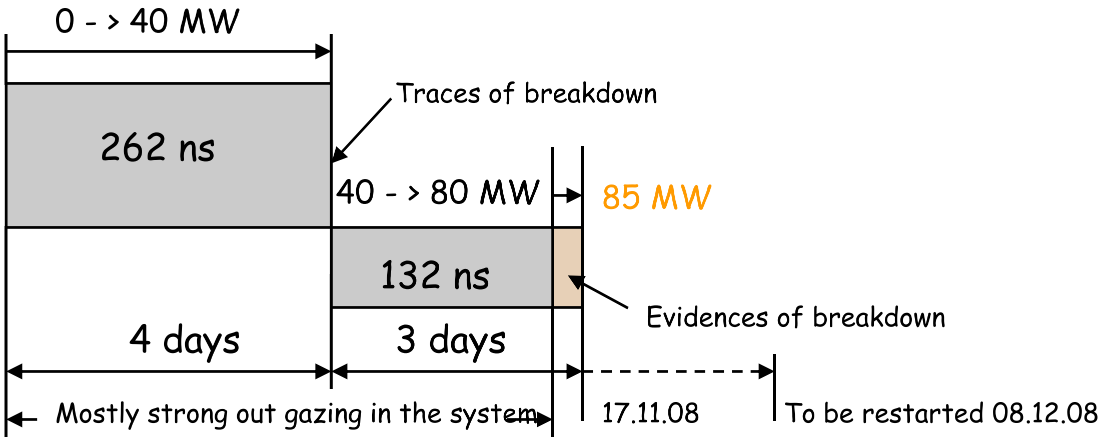
Typical RF pulse envelope in the ASTA compressed arm. The SLED II operates in dual mode regime

CLIC Power Extraction and Transfer Structure (PETS) high power tests at SLAC

	CLIC target	Processing status (17.11.08)
RF power. MW	135	85
Pulse length, ns	240 (170 flat top)	132 flat top

Assembly of the eight PETS bars.





0 - > 40 MW

262 ns

Traces of breakdown

40 - > 80 MW

85 MW

132 ns

Evidences of breakdown

4 days

3 days

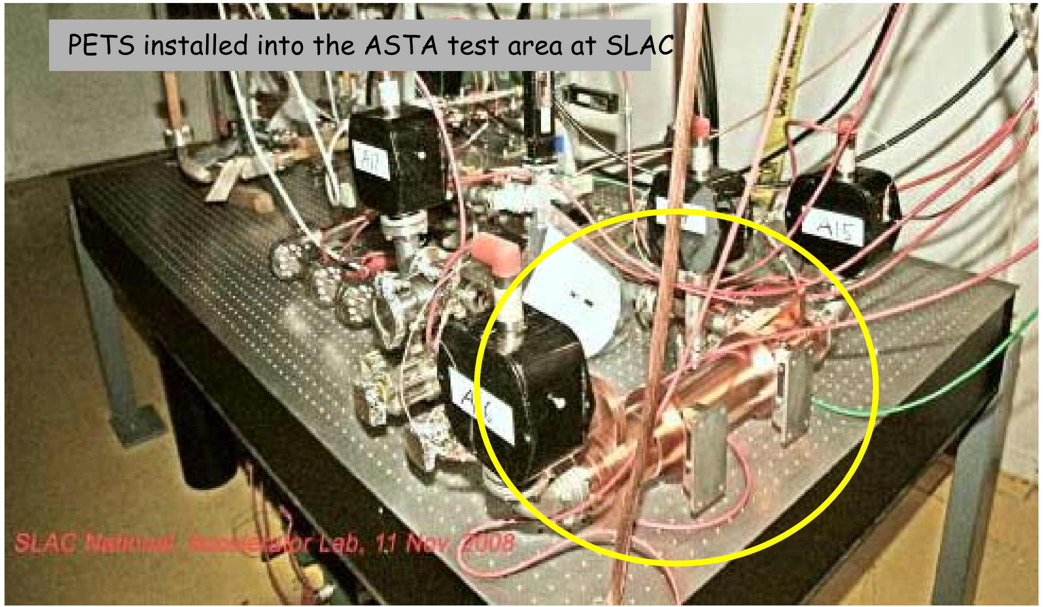
Mostly strong out gazing in the system

17.11.08

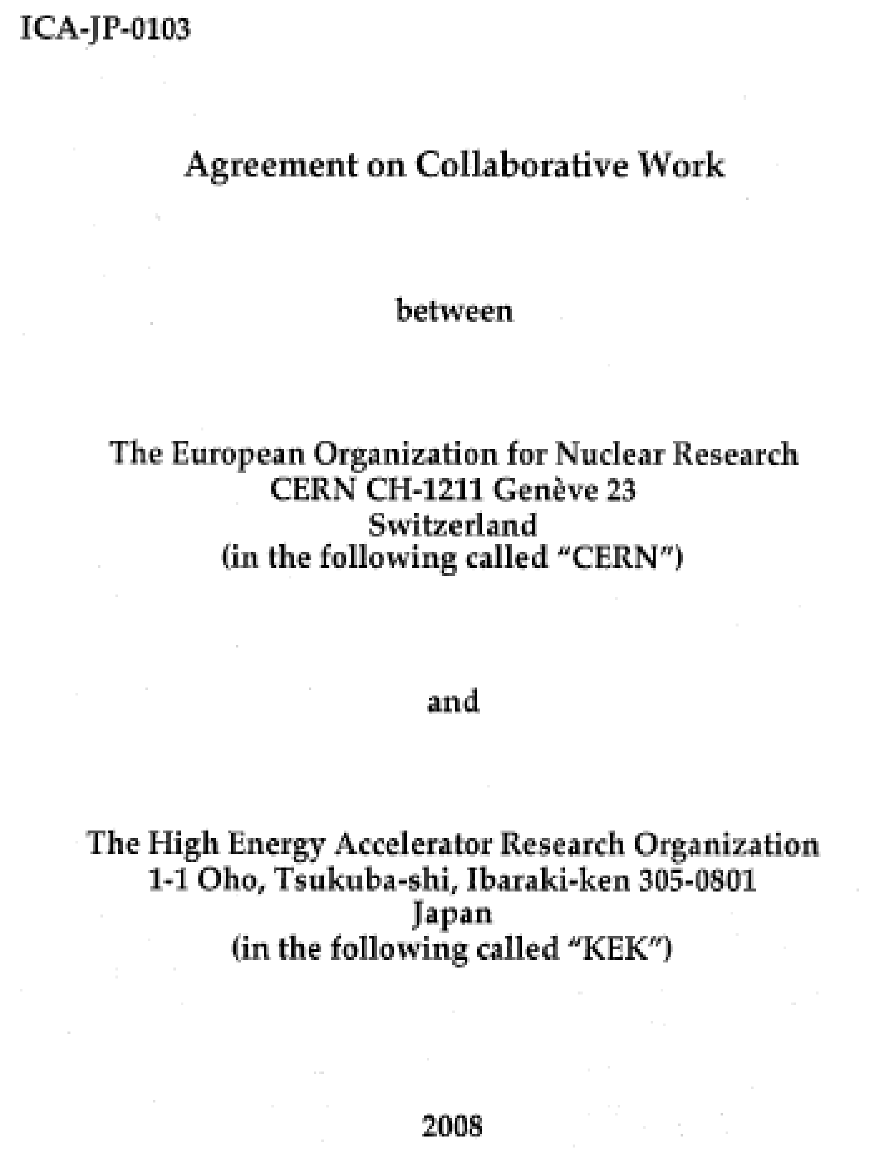
To be restarted 08.12.08

11.424 GHz PETS ready

PETS installed into the ASTA test area at SLAC



Collaboration with KEK



ICA-JP-0103

Agreement on Collaborative Work

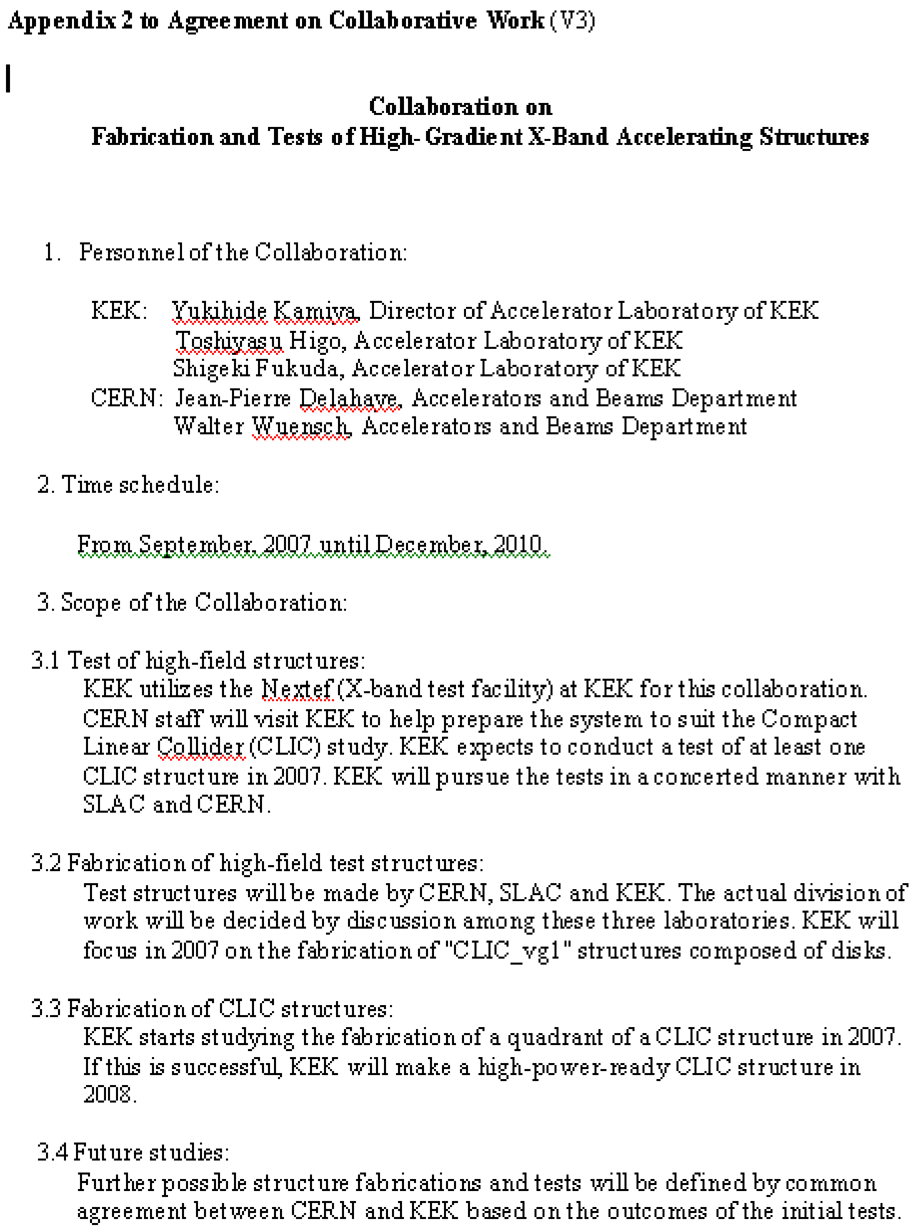
between

The European Organization for Nuclear Research
CERN CH-1211 Genève 23
Switzerland
(in the following called "CERN")

and

The High Energy Accelerator Research Organization
1-1 Oho, Tsukuba-shi, Ibaraki-ken 305-0801
Japan
(in the following called "KEK")

2008



Appendix 2 to Agreement on Collaborative Work (V3)

Collaboration on
Fabrication and Tests of High-Gradient X-Band Accelerating Structures

1. Personnel of the Collaboration:

KEK: Yukihide Kamiya, Director of Accelerator Laboratory of KEK
Toshiyasu Higo, Accelerator Laboratory of KEK
Shigeki Fukuda, Accelerator Laboratory of KEK
CERN: Jean-Pierre Delahaye, Accelerators and Beams Department
Walter Wuensch, Accelerators and Beams Department

2. Time schedule:

From September, 2007 until December, 2010.

3. Scope of the Collaboration:

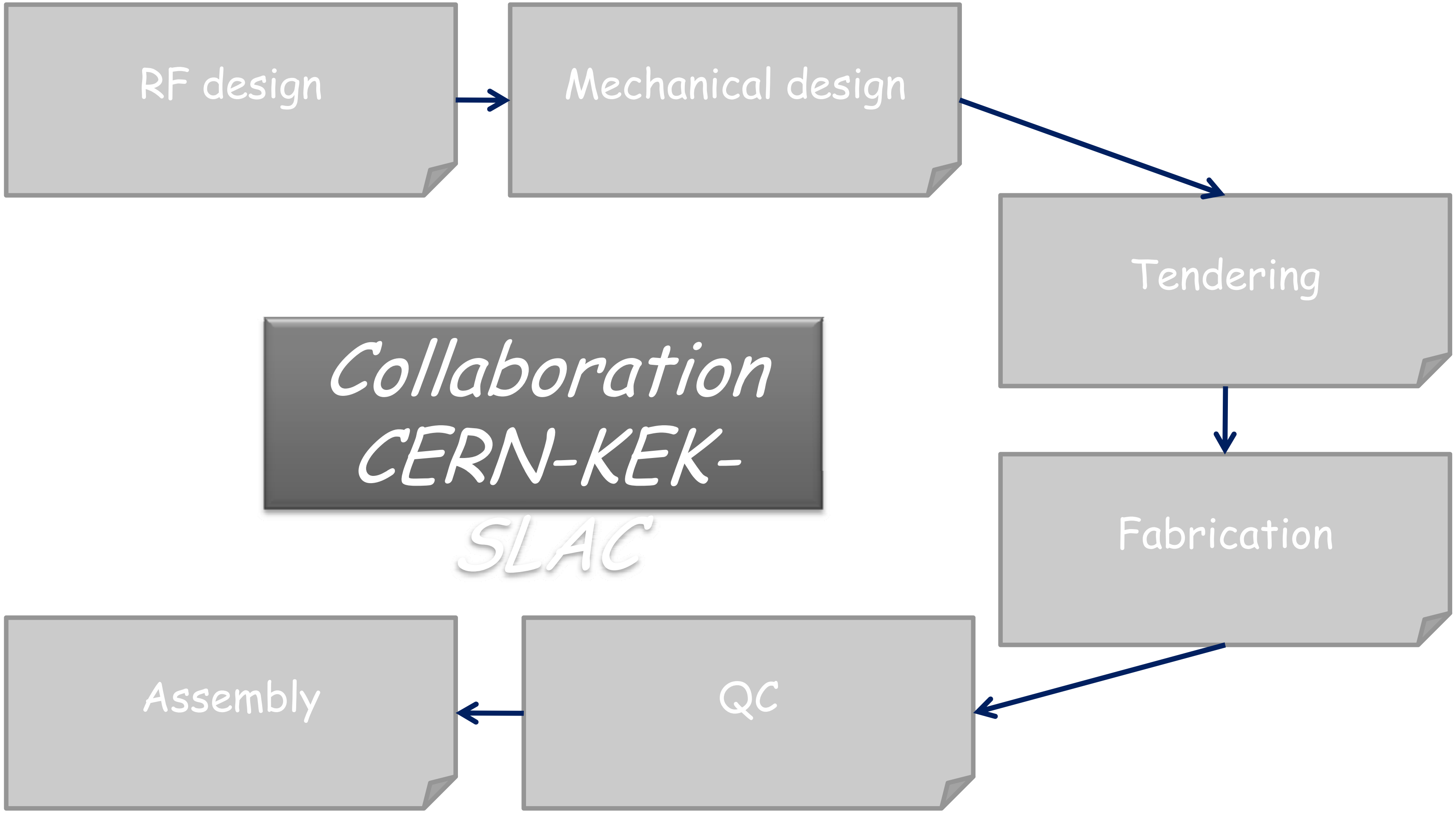
3.1 Test of high-field structures:
KEK utilizes the Nextef (X-band test facility) at KEK for this collaboration. CERN staff will visit KEK to help prepare the system to suit the Compact Linear Collider (CLIC) study. KEK expects to conduct a test of at least one CLIC structure in 2007. KEK will pursue the tests in a concerted manner with SLAC and CERN.

3.2 Fabrication of high-field test structures:
Test structures will be made by CERN, SLAC and KEK. The actual division of work will be decided by discussion among these three laboratories. KEK will focus in 2007 on the fabrication of "CLIC_vg1" structures composed of disks.

3.3 Fabrication of CLIC structures:
KEK starts studying the fabrication of a quadrant of a CLIC structure in 2007. If this is successful, KEK will make a high-power-ready CLIC structure in 2008.

3.4 Future studies:
Further possible structure fabrications and tests will be defined by common agreement between CERN and KEK based on the outcomes of the initial tests.

Structure production


RF design

Mechanical design

Tendering

Fabrication

QC

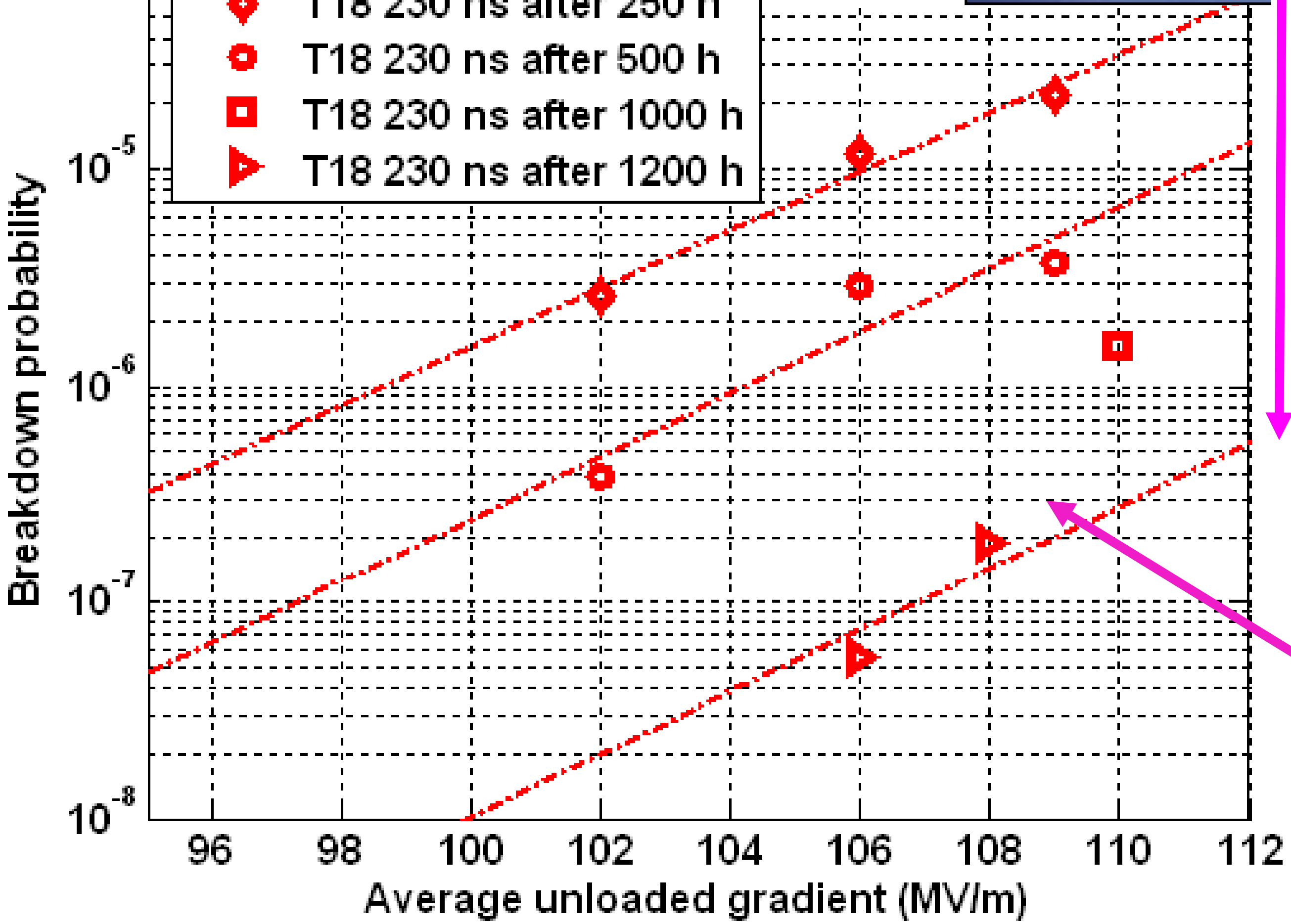
Assembly

Collaboration CERN-KEK-SLAC

Nominal CLIC Structure Performance demonstrated

A shining example of fruitful collaboration:

T18_VG2.4_disk: *Designed at CERN,*
(without damping) *Built at KEK,*
RF Tested at SLAC

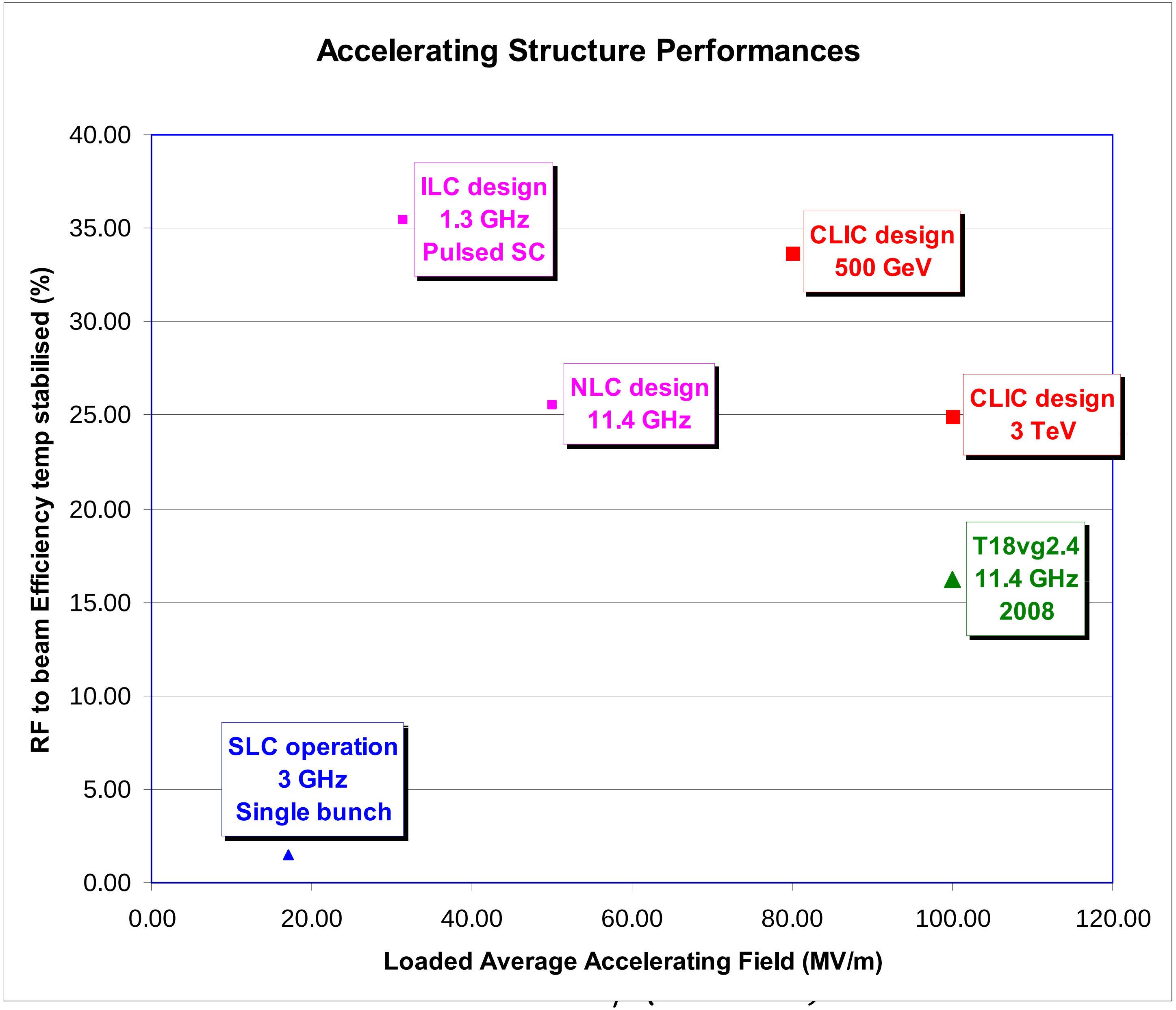


Improvement by RF conditionning

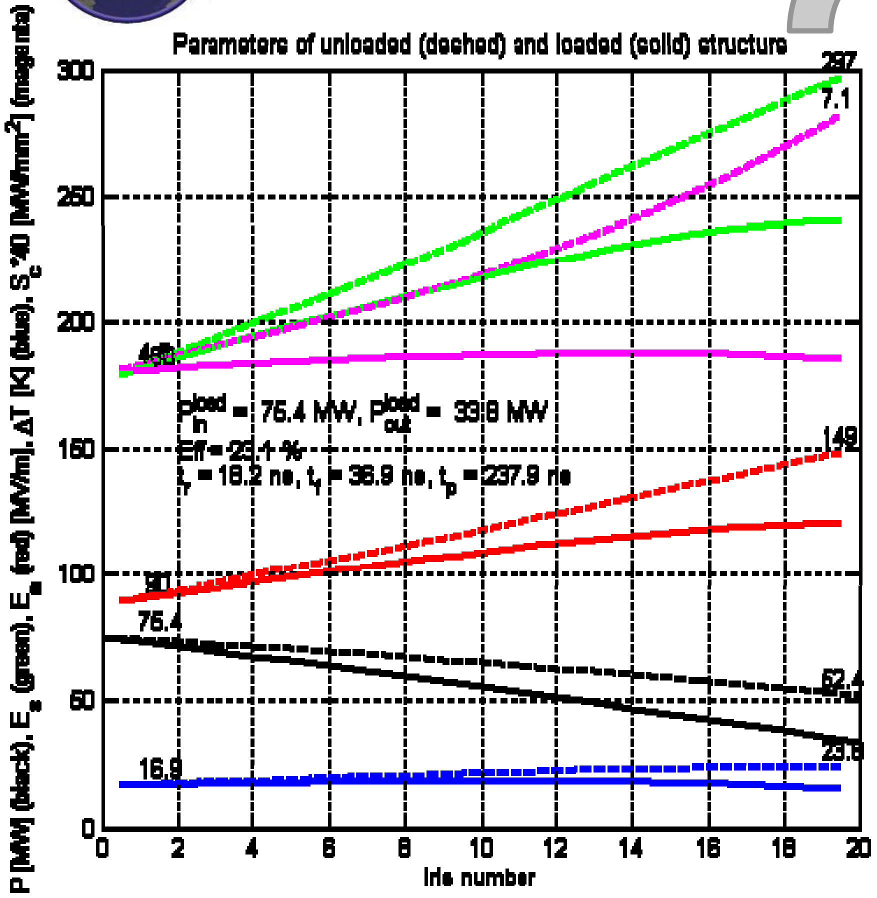
CLIC nominal

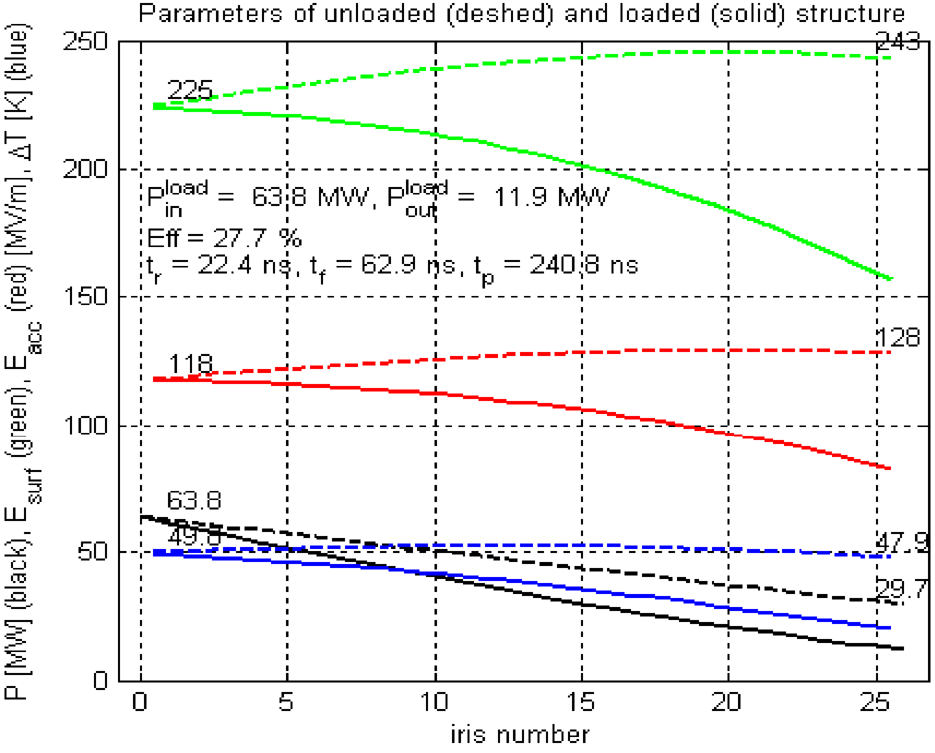
RF to beam transfer efficiency

(including power for temperature stabilisation)

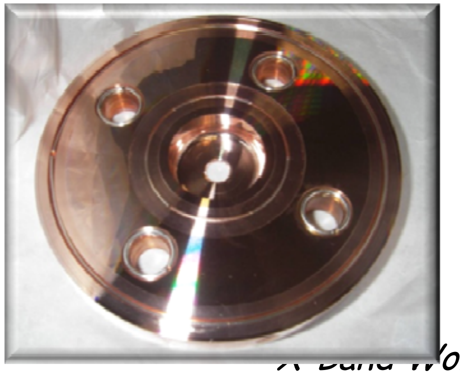


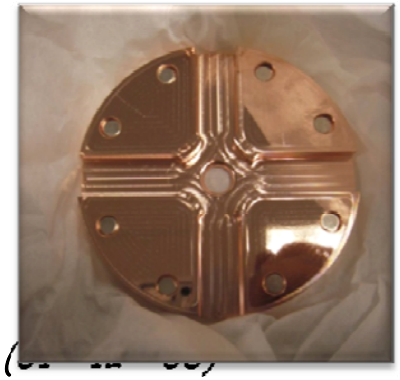
Achieved results to prototype CLIC structure





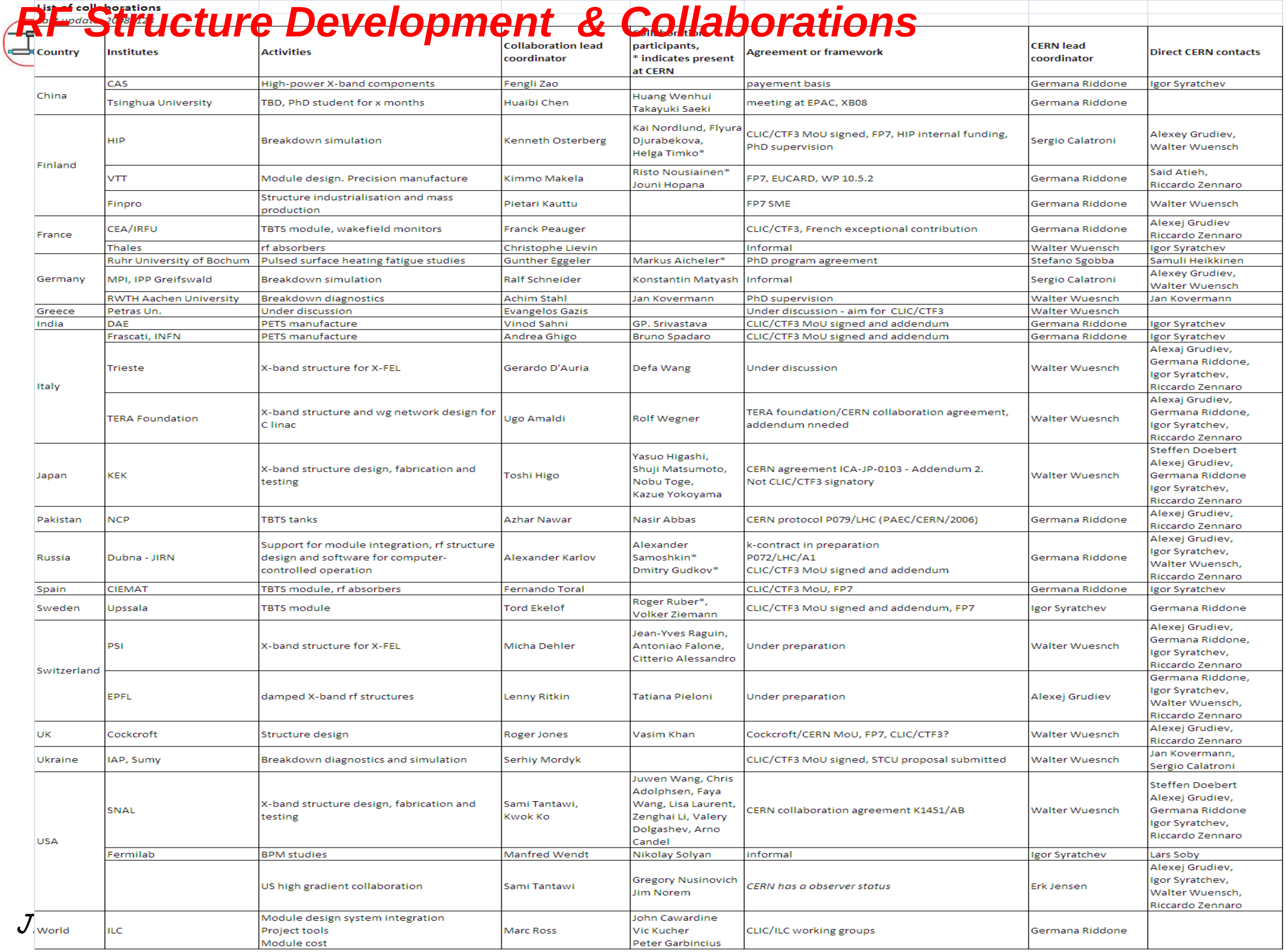
T18 test structure





CLIC prototype

RF Structure Development & Collaborations

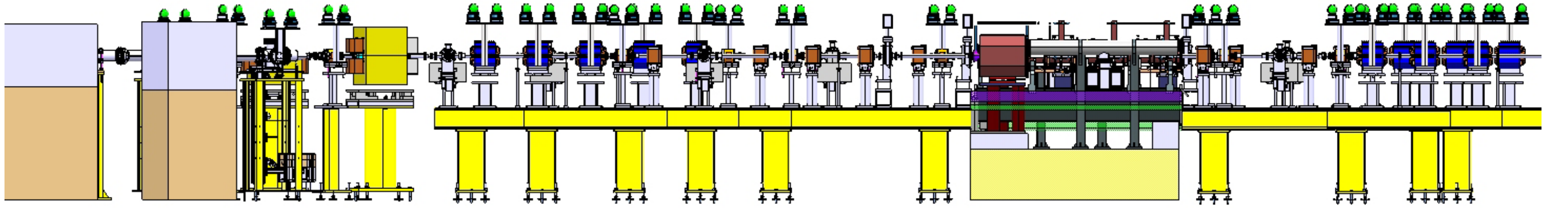


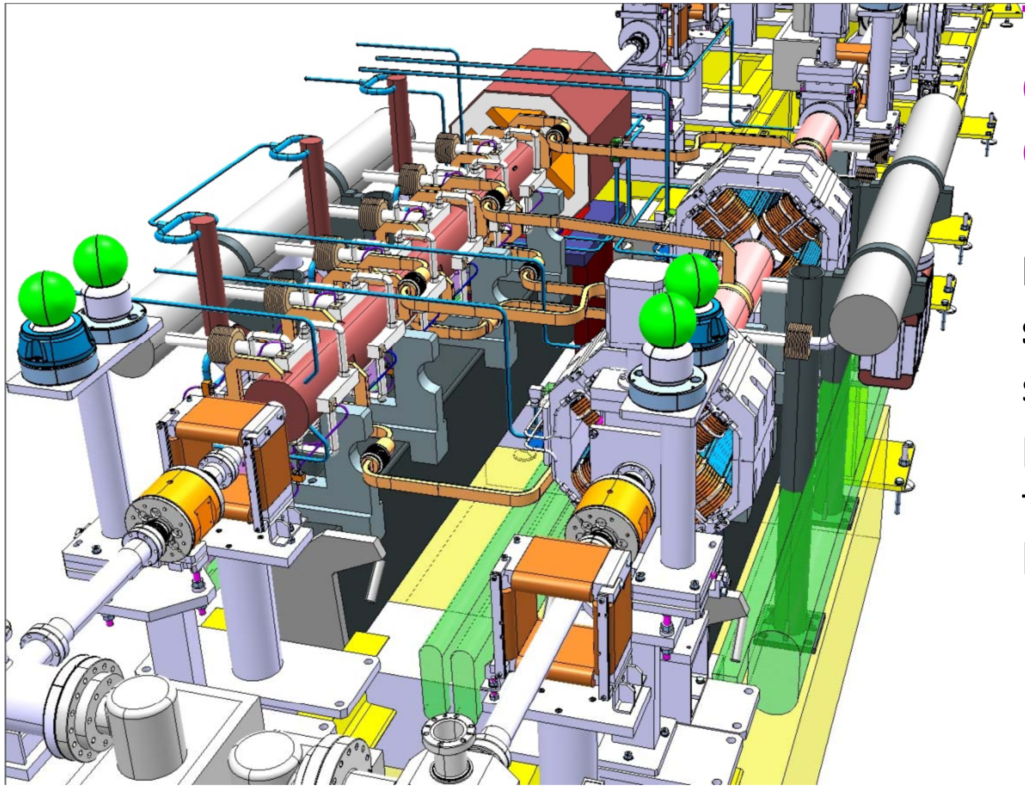
List of collaborations

Last update 2008[illegible]128

Country	Institutes	Activities	Collaboration lead coordinator	Collaboration participants, * indicates present at CERN	Agreement or framework	CERN lead coordinator	Direct CERN contacts
China	CAS	High-power X-band components	Fengli Zao		payement basis	Germana Riddone	Igor Syratchev
	Tsinghua University	TBD, PhD student for x months	Huaibi Chen	Huang Wenhui Takayuki Saeki	meeting at EPAC, XB08	Germana Riddone	
Finland	HIP	Breakdown simulation	Kenneth Osterberg	Kai Nordlund, Flyura Djurabekova, Helga Timko*	CLIC/CTF3 MoU signed, FP7, HIP internal funding, PhD supervision	Sergio Calatroni	Alexey Grudiev, Walter Wuensch
	VTT	Module design. Precision manufacture	Kimmo Makela	Risto Nousiainen* Jouni Hopana	FP7, EUCARD, WP 10.5.2	Germana Riddone	Said Atieh, Riccardo Zennaro
	Finpro	Structure industrialisation and mass production	Pietari Kauttu		FP7 SME	Germana Riddone	Walter Wuensch
France	CEA/IRFU	TBTS module, wakefield monitors	Franck Peauger		CLIC/CTF3, French exceptional contribution	Germana Riddone	Alexej Grudiev Riccardo Zennaro
	Thales	rf absorbers	Christophe Lievin		Informal	Walter Wuensch	Igor Syratchev
Germany	Ruhr University of Bochum	Pulsed surface heating fatigue studies	Gunther Eggeler	Markus Aicheler*	PhD program agreement	Stefano Sgobba	Samuli Heikkinen
	MPI, IPP Greifswald	Breakdown simulation	Ralf Schneider	Konstantin Matyash	Informal	Sergio Calatroni	Alexey Grudiev, Walter Wuensch
	RWTH Aachen University	Breakdown diagnostics	Achim Stahl	Jan Kovermann	PhD supervision	Walter Wuesnch	Jan Kovermann
Greece	Petras Un.	Under discussion	Evangelos Gazis		Under discussion - aim for CLIC/CTF3	Walter Wuesnch	
India	DAE	PETS manufacture	Vinod Sahni	GP. Srivastava	CLIC/CTF3 MoU signed and addendum	Germana Riddone	Igor Syratchev
Italy	Frascati, INFN	PETS manufacture	Andrea Ghigo	Bruno Spadaro	CLIC/CTF3 MoU signed and addendum	Germana Riddone	Igor Syratchev
	Trieste	X-band structure for X-FEL	Gerardo D'Auria	Defa Wang	Under discussion	Walter Wuesnch	Alexaj Grudiev, Germana Riddone, Igor Syratchev, Riccardo Zennaro
	TERA Foundation	X-band structure and wg network design for C linac	Ugo Amaldi	Rolf Wegner	TERA foundation/CERN collaboration agreement, addendum nneded	Walter Wuesnch	Alexaj Grudiev, Germana Riddone, Igor Syratchev, Riccardo Zennaro
Japan	KEK	X-band structure design, fabrication and testing	Toshi Higo	Yasuo Higashi, Shuji Matsumoto, Nobu Toge, Kazue Yokoyama	CERN agreement ICA-JP-0103 - Addendum 2. Not CLIC/CTF3 signatory	Walter Wuesnch	Steffen Doebert Alexej Grudiev, Germana Riddone Igor Syratchev, Riccardo Zennaro
Pakistan	NCP	TBTS tanks	Azhar Nawar	Nasir Abbas	CERN protocol P079/LHC (PAEC/CERN/2006)	Germana Riddone	Alexej Grudiev, Riccardo Zennaro
Russia	Dubna - JIRN	Support for module integration, rf structure design and software for computer-controlled operation	Alexander Karlov	Alexander Samoshkin* Dmitry Gudkov*	k-contract in preparation P072/LHC/A1 CLIC/CTF3 MoU signed and addendum	Germana Riddone	Alexej Grudiev, Igor Syratchev, Walter Wuensch, Riccardo Zennaro
Spain	CIEMAT	TBTS module, rf absorbers	Fernando Toral		CLIC/CTF3 MoU, FP7	Germana Riddone	Igor Syratchev
Sweden	Upssala	TBTS module	Tord Ekelof	Roger Ruber*, Volker Ziemann	CLIC/CTF3 MoU signed and addendum, FP7	Igor Syratchev	Germana Riddone
Switzerland	PSI	X-band structure for X-FEL	Micha Dehler	Jean-Yves Raguin, Antoniao Falone, Citterio Alessandro	Under preparation	Walter Wuesnch	Alexej Grudiev, Germana Riddone, Igor Syratchev, Riccardo Zennaro
	EPFL	damped X-band rf structures	Lenny Ritkin	Tatiana Pieloni	Under preparation	Alexej Grudiev	Germana Riddone, Igor Syratchev, Walter Wuensch, Riccardo Zennaro
UK	Cockcroft	Structure design	Roger Jones	Vasim Khan	Cockcroft/CERN MoU, FP7, CLIC/CTF3?	Walter Wuesnch	Alexej Grudiev, Riccardo Zennaro
Ukraine	IAP, Sumy	Breakdown diagnostics and simulation	Serhiy Mordyk		CLIC/CTF3 MoU signed, STCU proposal submitted	Walter Wuesnch	Jan Kovermann, Sergio Calatroni
USA	SNAL	X-band structure design, fabrication and testing	Sami Tantawi, Kwok Ko	Juwen Wang, Chris Adolphsen, Faya Wang, Lisa Laurent, Zenghai Li, Valery Dolgashev, Arno Candel	CERN collaboration agreement K1451/AB	Walter Wuesnch	Steffen Doebert Alexej Grudiev, Germana Riddone Igor Syratchev, Riccardo Zennaro
	Fermilab	BPM studies	Manfred Wendt	Nikolay Solyan	informal	Igor Syratchev	Lars Soby
		US high gradient collaboration	Sami Tantawi	Gregory Nusinovich Jim Norem	*CERN has a observer status*	Erk Jensen	Alexej Grudiev, Igor Syratchev, Walter Wuensch, Riccardo Zennaro
World	ILC	Module design system integration Project tools Module cost	Marc Ross	John Cawardine Vic Kucher Peter Garbincius	CLIC/ILC working groups	Germana Riddone	

Two Beam Module tests in CTF3/CLEX





Two Beam Test Stand: Contribution of Swedish Collaboration: Uppsala Univ.

Design and integration of different sub-systems, i.e. to simultaneously satisfy requirements of highest possible gradient, power handling, tight mechanical tolerances and heavy HOM damping

Present collaborations on Two Beam Module

- PETS fabrication → CIEMAT, India AEI
- Alignment, wake fields, and HOM damping → Un. of Manchester
- Equipment to diagnose the electrons, ions and light → UPPSALA
- Accelerating structure precise assembly → HIP
- Main beam quadrupole stabilisation → LAPP, UOXL-DL
- Accelerating structures with wakefield monitors → CEA-Saclay
- Vacuum equipment → Pakistan NCP
- Design and procurement of accelerating structures → SLAC/KEK
- Design and procurement of alignment systems components → Nikhef
- System integration → DUBNA

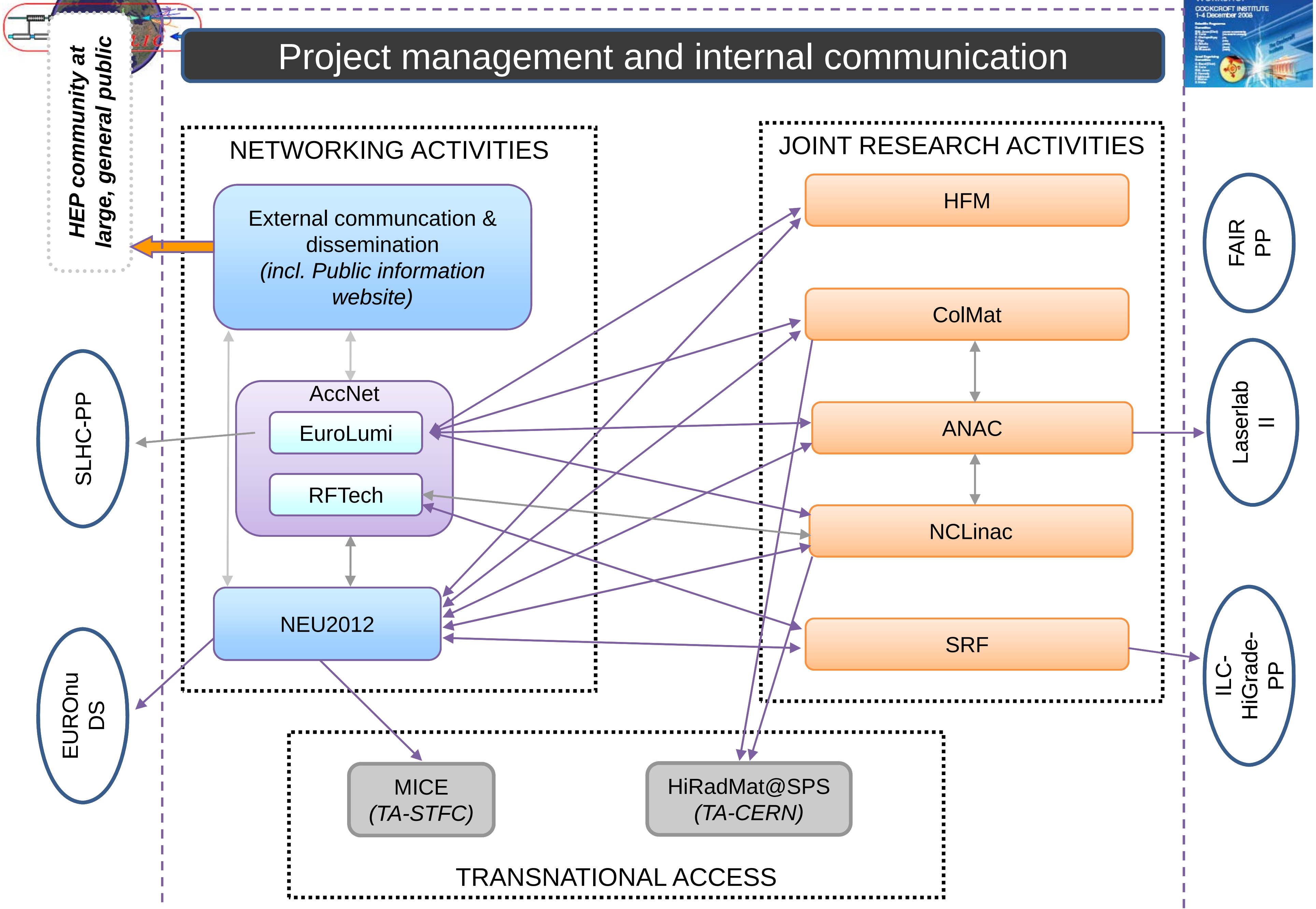
Technical issues under study (opportunities for collaborations)

- **System Integration:** several systems with stringent requirements
- **Cooling:** high power dissipation (7 kW per 2-m long module) → thermal and mechanical stabilization issues, alignment issues
- **Vacuum:** < 10^{-8} mbar, structure design shall take into account conductance requirements
- **Alignment:** Micron range accelerating structure pre-alignment needs precise fabrication and assembly
- **Stabilization:** main beam quadrupole shall be stabilized at 1 nm (f > 1 Hz) → effect of ground motion, cooling vibrations → feedback system design
- **Supports:** design of girder shall take into account stabilization and alignment
- **Interconnections:** challenging design in limited space and with tight vacuum and rf requirements
- **RF distribution:** development and optimization of inter-beam components
- **Tunnel integration**: transport and installation, access and maintenance, connections to utilities

FP7 - EuCARD

- *European Coordination of Accelerator Research and Development*
- EuCARD is an “Integrating Activity” (IA) supported by the European Commission (EC)
- EuCARD is the successor of CARE
- EuCARD is consisting of 11 Work Packages:
  - 5 “Joint Research Activites”
  - 3 “Networking Activites”
  - 2 “Transnational Access Activities”
  - Project Management (see next slide)

Project management and internal communication



FP7 - EuCARD

- EuCARD is coordinated by CERN
- 37 “beneficiaries” (participating labs, universities and companies) from 12 European countries.
- Duration: April 2009 – March 2013
- Overall budget: 33 M€, EC contribution: 10 M€
- Details at: https://eucard.web.cern.ch/EuCARD/index.html
- Present status: finalizing *Grant Agreement* with EC and *Consortium Agreement* with the partners.

Goals of EuCARD WP9 “NCLinac”

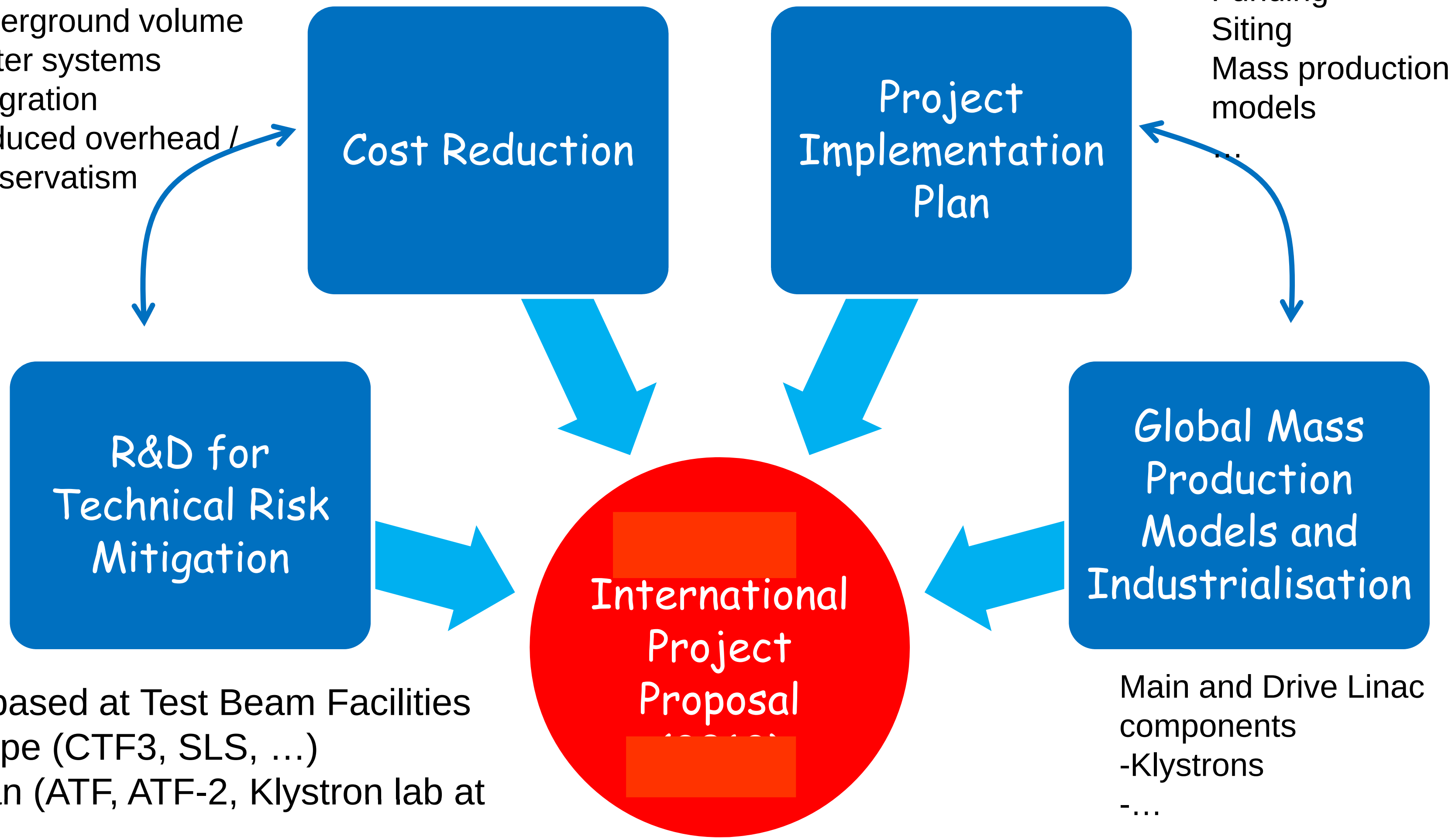
NCLinac concentrates on the identified issues in R&D to prepare for the future HEP Particle colliders that can reach beyond the LHC.
The issues to be addressed are primarily *i)* how to reach a high accelerating gradient reliably and *ii)* how to stabilize the beams and the machine to allow collisions of nm-sized beams without loss of luminosity. For the first, NCLinac limits its scope to normal conducting accelerator structures, complementary to work on superconducting accelerator structures foreseen in the work package SRF. For the latter issue, synergy is actively sought and implemented between the superconducting (SC) and normal conducting (NC) linear collider approaches.
NCLinac is complementing a presently ongoing program of R&D; it uses and enforces readily established global research networks like the CLIC/CTF3 collaboration or the Global Design Effort (GDE) for the ILC. The high-gradient research will be coordinated with the existing US High-Gradient Collaboration. NCLinac will improve and make available for a wider community of researchers purpose built and recognized world-class Research Infrastructures like the CLIC Test Facility CTF3 at CERN and the DAΦNE facility at Frascati, but also the world-wide only facility to address issues for extremely small emittances, ATF2 at KEK in Japan, is included.

EuCARD WP9 “NCLinac”

- Full name: ***“Technology for normal conducting higher energy linear colliders”***
- 5 tasks:
  - NCLinac Coordination and Communication
  - Normal conducting High Gradient Cavities
    PETS, alignment & HOM’s, breakdown simulation, BD diagnostics, precise assembly
  - Linac and Final Focus Stabilisation
    Quadrupole mock-up, FF test-stand
  - Beam Delivery System
    tuning procedures at ATF2, high-precision BPM’s, Laser-wire
  - Drive Beam Phase control
    20 fs RF monitor, electro-optical monitor
- Partners: CERN, CIEMAT, CNRS, INFN, PSI, RHUL, STFC, UNIMAN, UOXF-DL, UU
- **Resources: 6.5 MEuros, 540 persons-years**

CLIC Technical Design (2011-2015)

(inspired from ILC priorities courtesy of N.Walker)



Structure R&D
Reduction of underground volume
Better systems integration
Reduced overhead / conservatism
…

International governance
Funding
Siting
Mass production models
…

Cost Reduction

Project Implementation Plan

R&D for Technical Risk Mitigation

[redacted]
International Project Proposal
[redacted]

Global Mass Production Models and Industrialisation

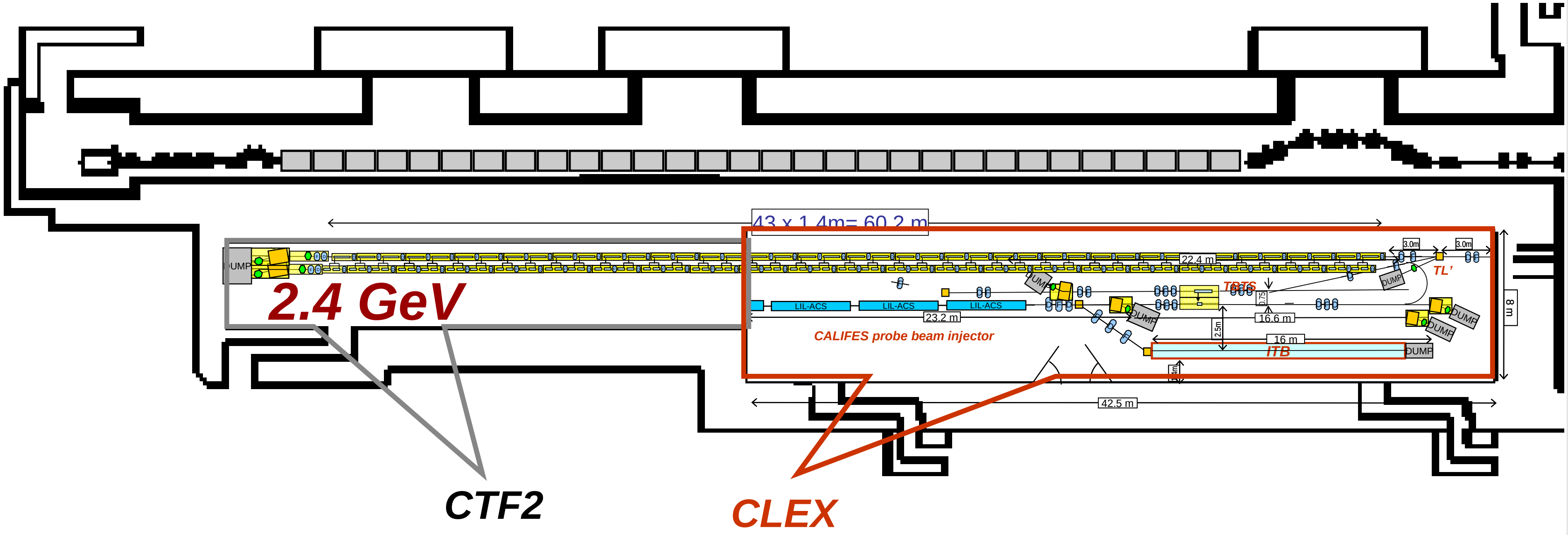
R&D based at Test Beam Facilities
- Europe (CTF3, SLS, …)
- Japan (ATF, ATF-2, Klystron lab at KEK)
- US (SLAC,CESR-TA at Cornell)

Main and Drive Linac components
-Klystrons
-…

Options for long term use of CTF3:

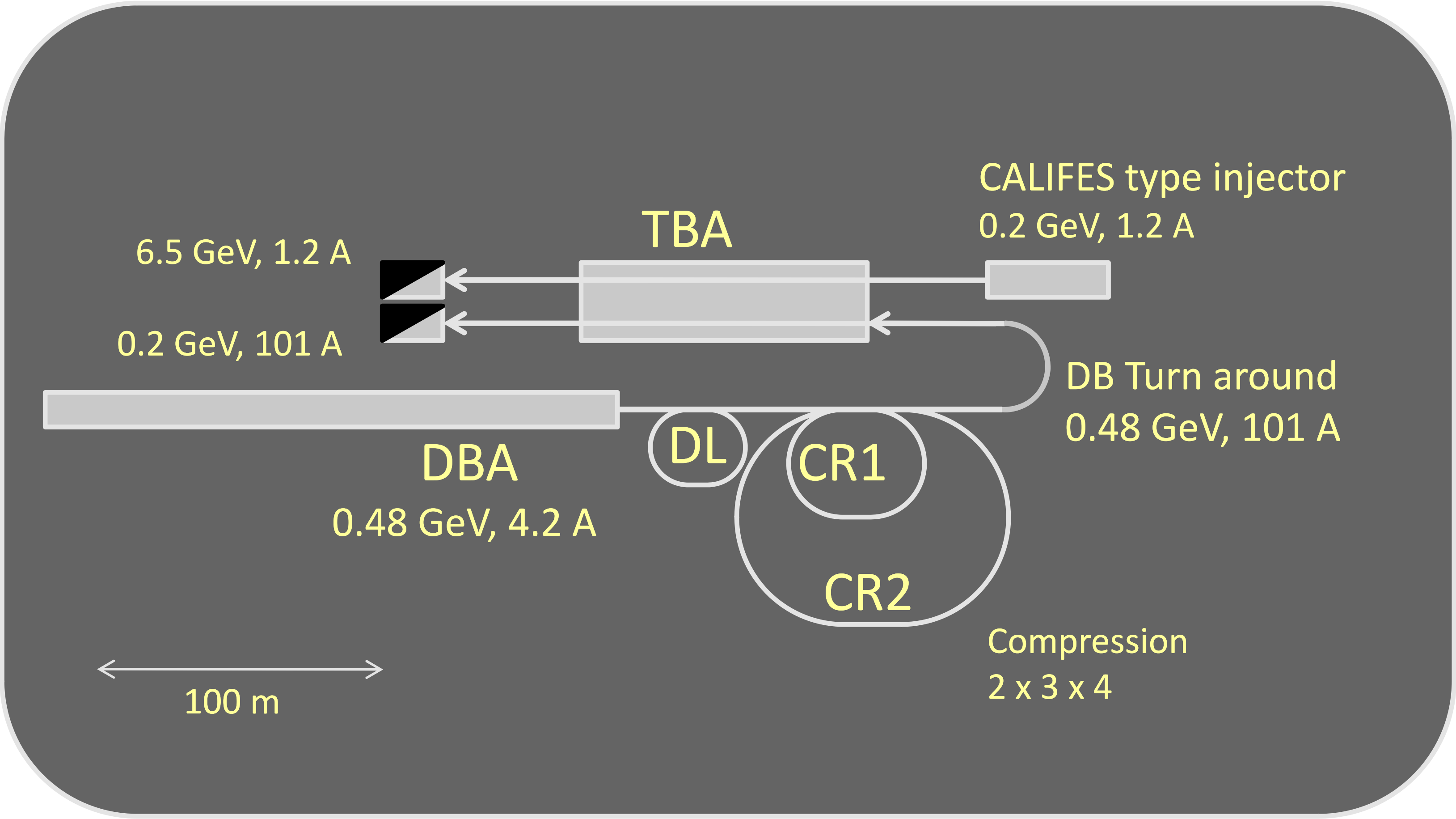
2.4 GeV Two beam X-band linac ?

The ultimate, only building limited two beam accelerator in CTF3 !



A next facility towards CLIC: CLIC0 ?

6.5 GeV Two Beam Accelerator



Applications and Industrialisation

X–FEL facilities

SC 1.3 GHz L band

European XFEL
DESY 2013

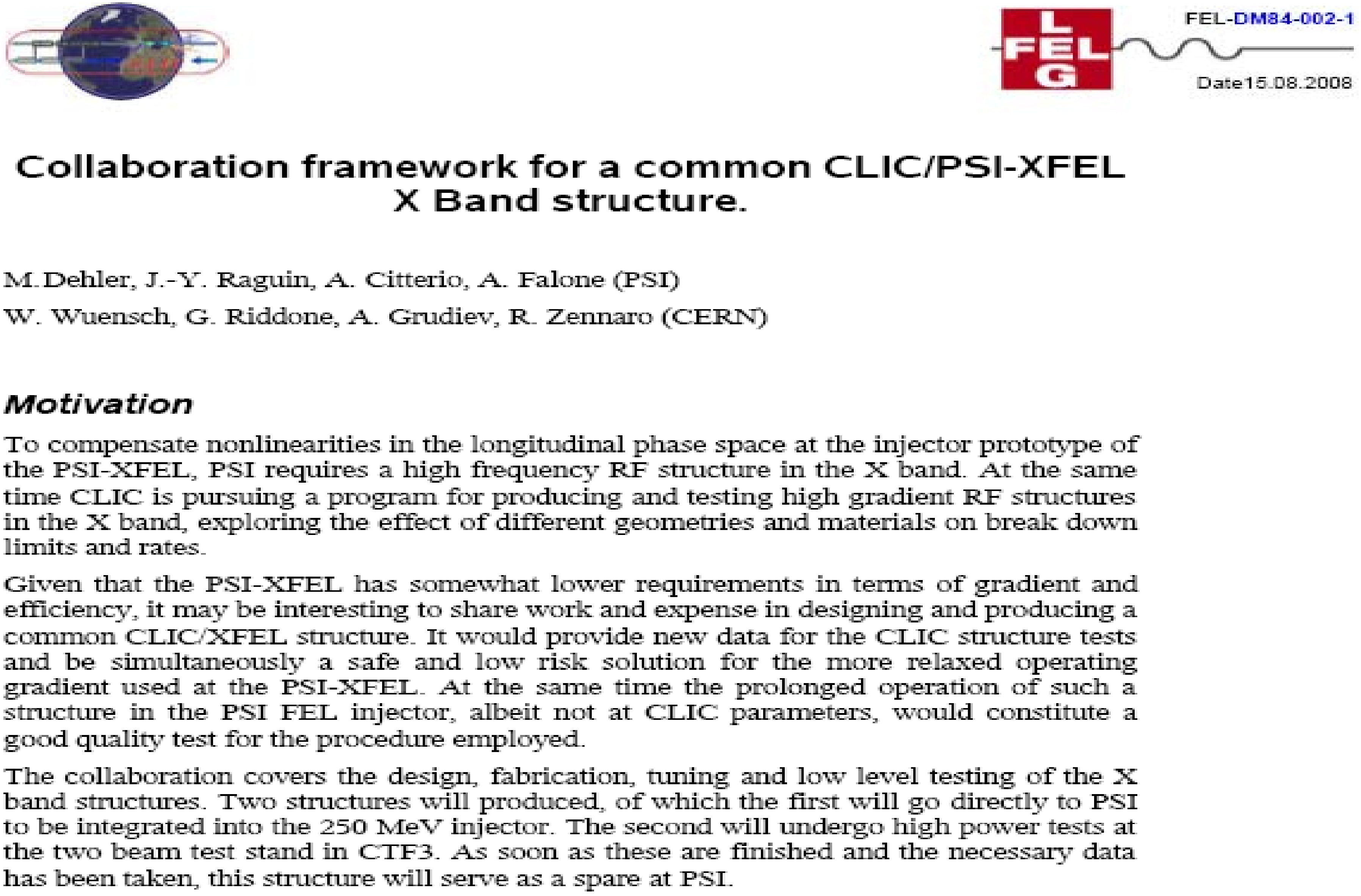
NC 5.7 GHz C band

Japan
SCSS – SPring8 2010

NC 3 GHz S band

USA
LCLS – SLAC 2009

X-Band structures for PSI/X-FEL and ELETTRA Linac based X-FEL



FEL-DM84-002-1

Date15.08.2008

Collaboration framework for a common CLIC/PSI-XFEL X Band structure.

M.Dehler, J.-Y. Raguin, A. Citterio, A. Falone (PSI)

W. Wuensch, G. Riddone, A. Grudiev, R. Zennaro (CERN)

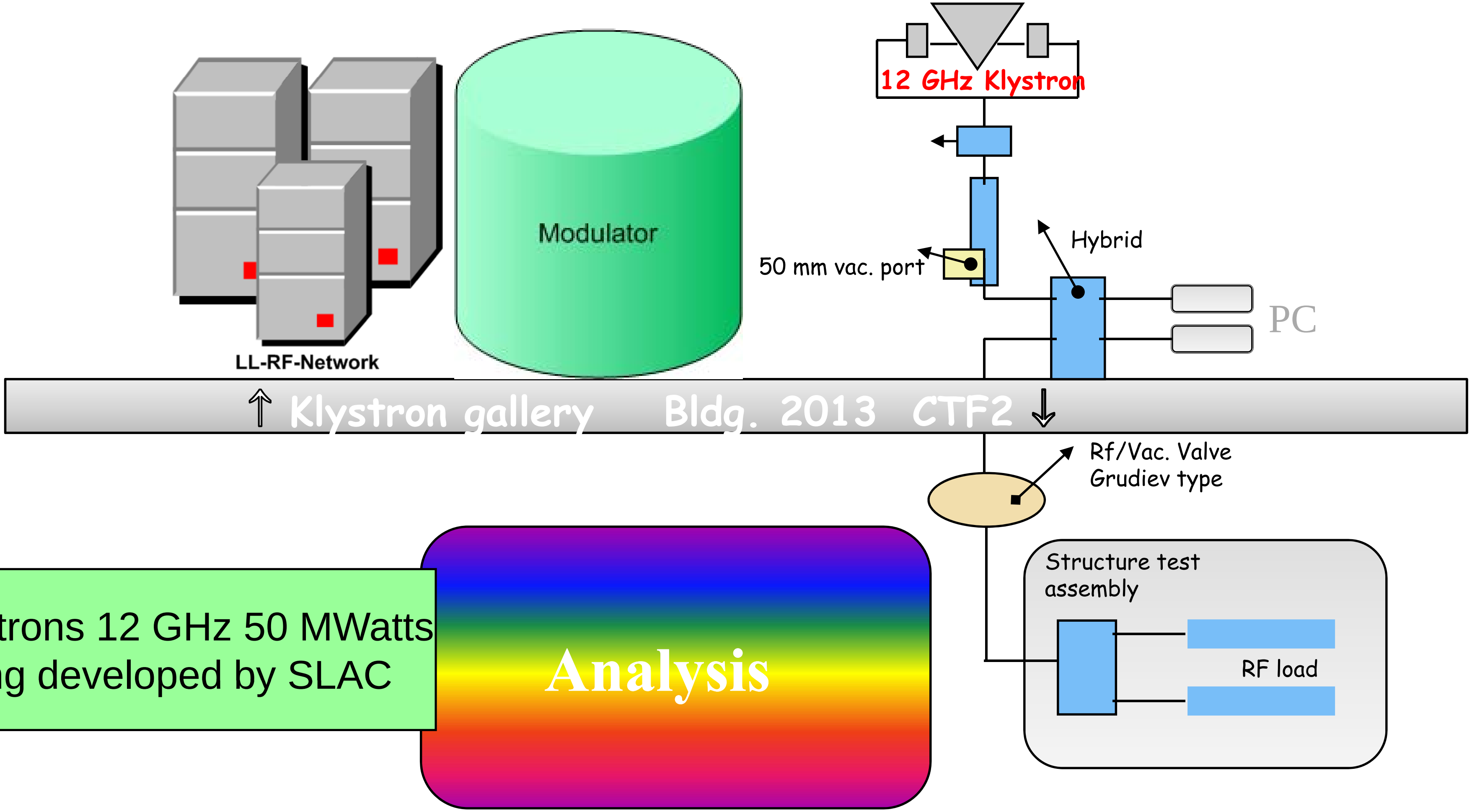
Motivation

To compensate nonlinearities in the longitudinal phase space at the injector prototype of the PSI-XFEL, PSI requires a high frequency RF structure in the X band. At the same time CLIC is pursuing a program for producing and testing high gradient RF structures in the X band, exploring the effect of different geometries and materials on break down limits and rates.

Given that the PSI-XFEL has somewhat lower requirements in terms of gradient and efficiency, it may be interesting to share work and expense in designing and producing a common CLIC/XFEL structure. It would provide new data for the CLIC structure tests and be simultaneously a safe and low risk solution for the more relaxed operating gradient used at the PSI-XFEL. At the same time the prolonged operation of such a structure in the PSI FEL injector, albeit not at CLIC parameters, would constitute a good quality test for the procedure employed.

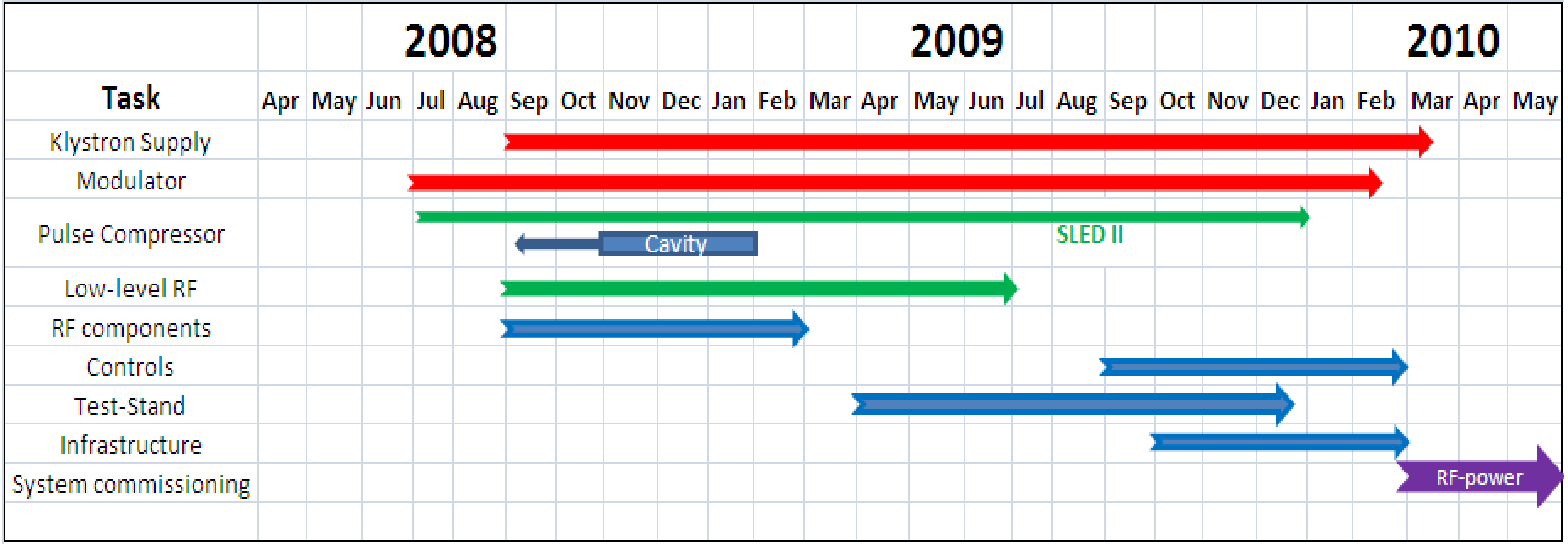
The collaboration covers the design, fabrication, tuning and low level testing of the X band structures. Two structures will produced, of which the first will go directly to PSI to be integrated into the 250 MeV injector. The second will undergo high power tests at the two beam test stand in CTF3. As soon as these are finished and the necessary data has been taken, this structure will serve as a spare at PSI.

12 GHz Klystron based RF power source
X-b Structure Test-Stand at CERN (and later CEA)
X-b Structure Operation at PSI and Trieste



5 Klystrons 12 GHz 50 MWatts being developed by SLAC

12 GHz Test-Stand Schedule
(In-kind contribution of CEA/France)

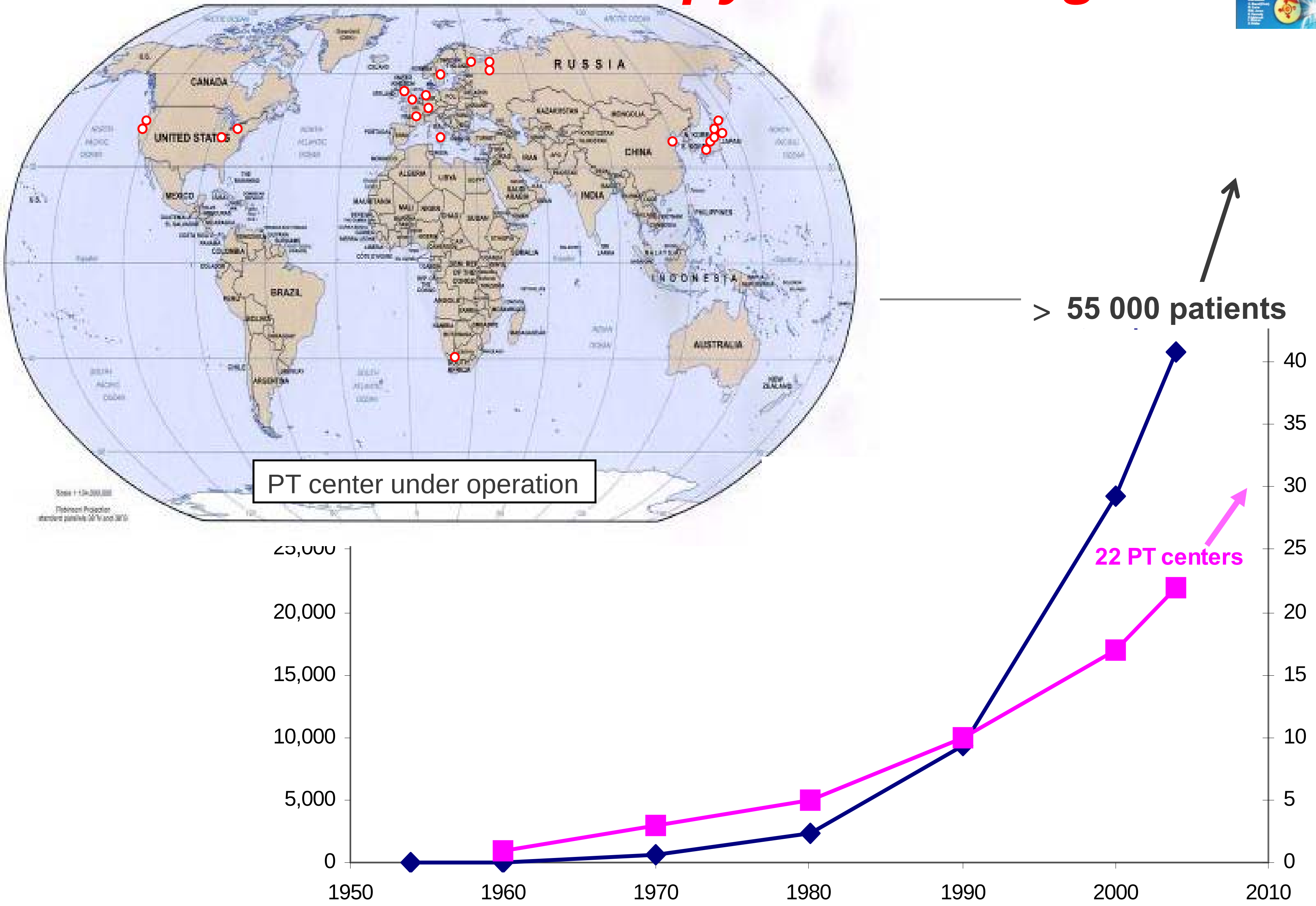


LINACS FOR HADRONTHERAPY:
a 12 GHz
CArbon BOoster for Therapy In Oncology

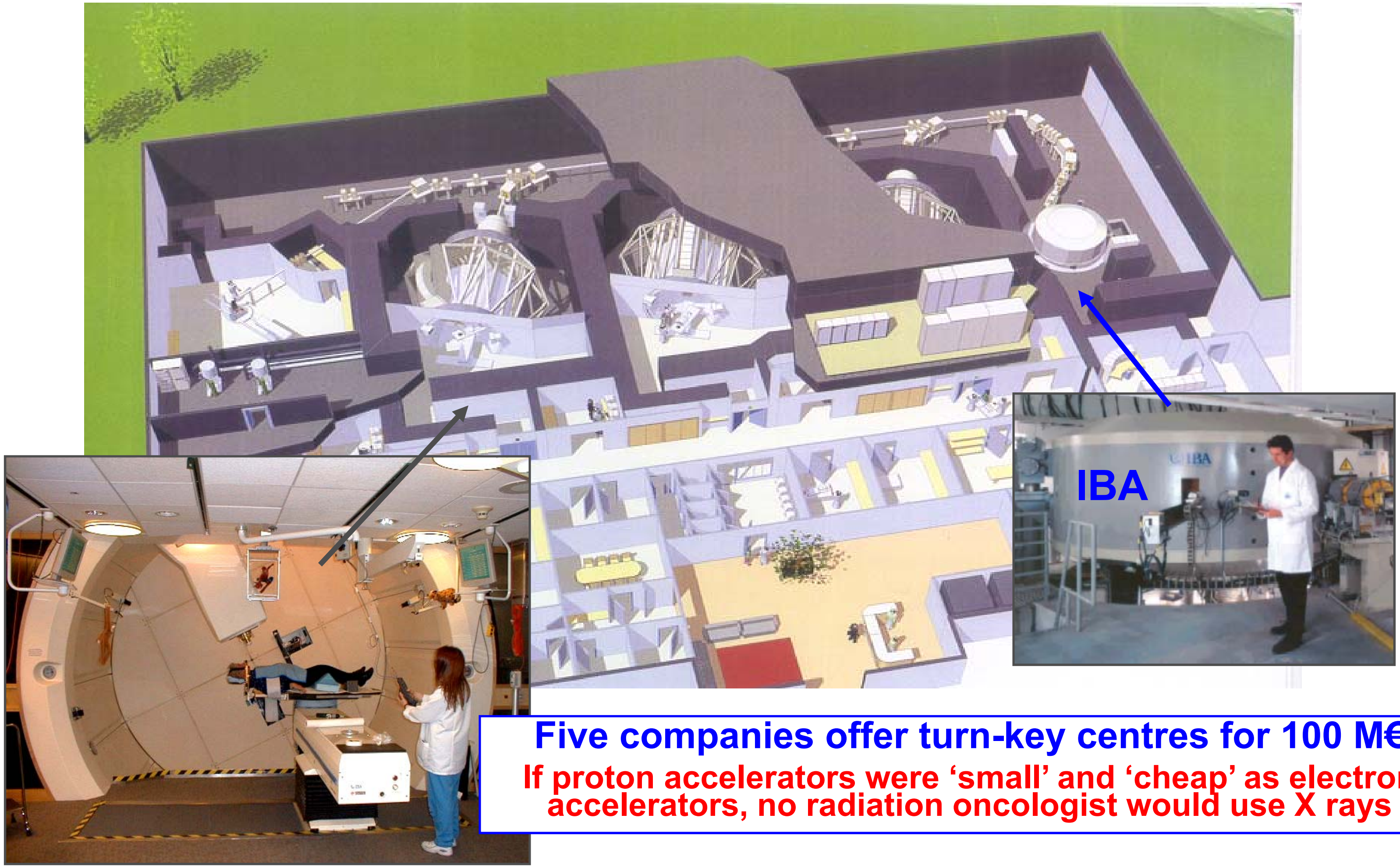
Ugo Amaldi

TERA FOUNDATION – Novara - Italy

Protontherapy is booming



Typical Centre for Hadron and Light Ions Therapy:

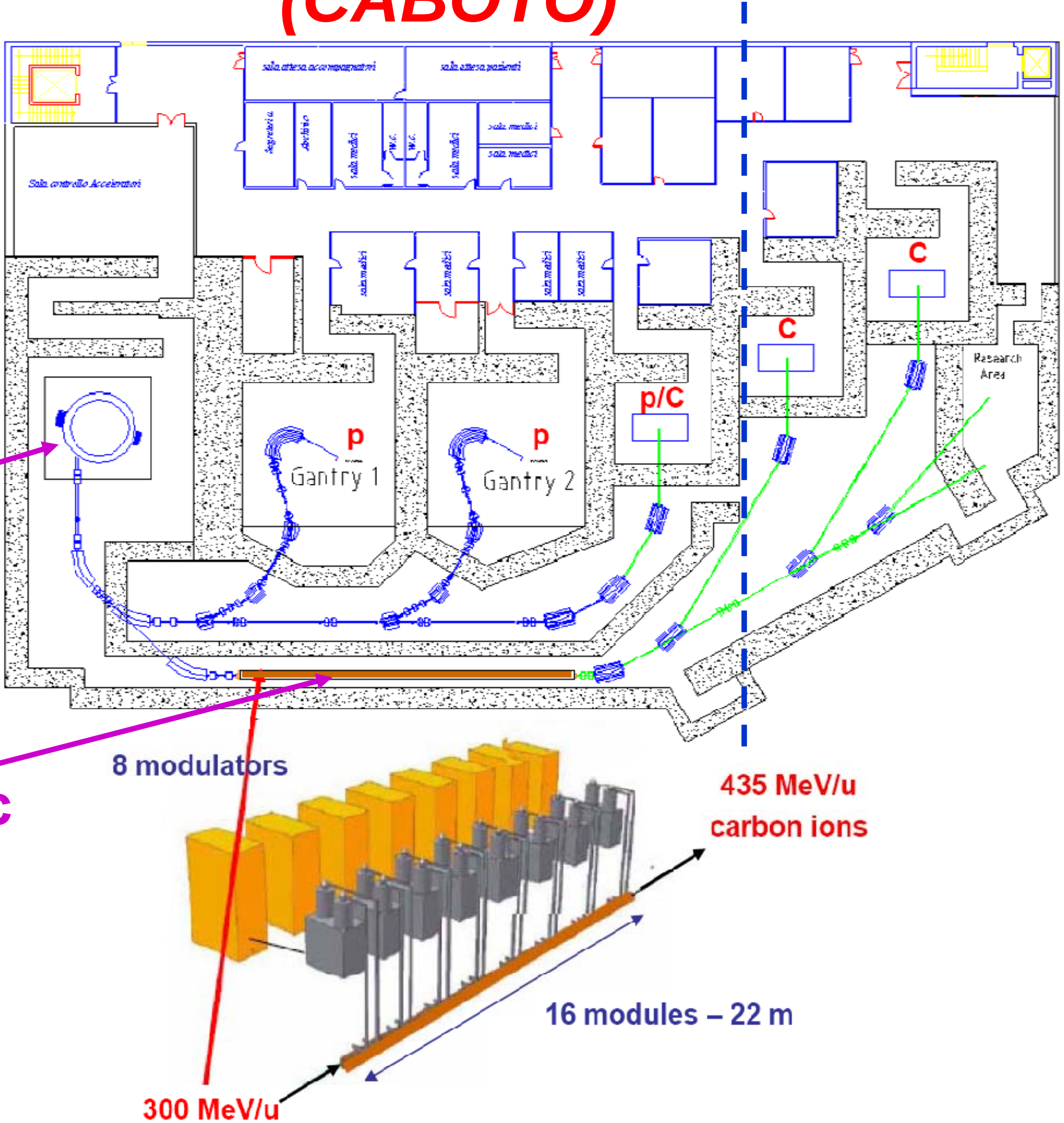


Five companies offer turn-key centres for 100 M€

If proton accelerators were 'small' and 'cheap' as electron accelerators, no radiation oncologist would use X rays

CArbon BOoster Therapy in Oncology (CABOTO)

TERA



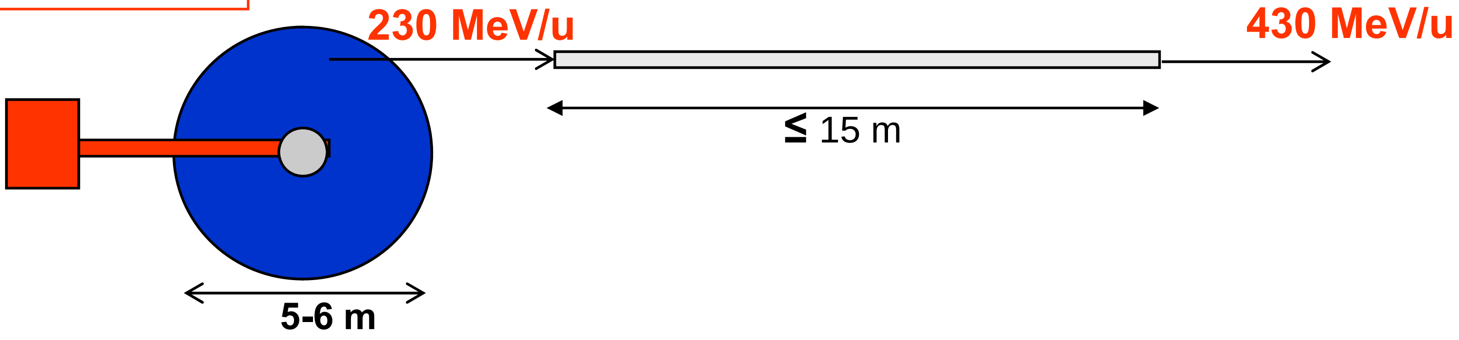
SC cyclotron

NC Linac

CABOTO at 12 GHz for reduced length and power consumption (CNAO consumes 3-4 MW!)

SC EBIS source by
DREEBIT – Dresden
300-400 Hz – 10^7 C/pulse

400 MV – 12 GHz linac
≤ 1 µs pulses

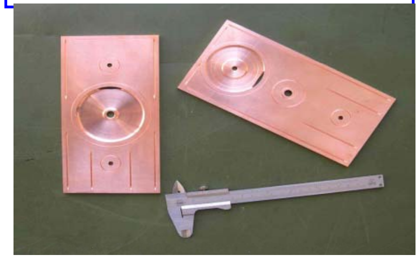


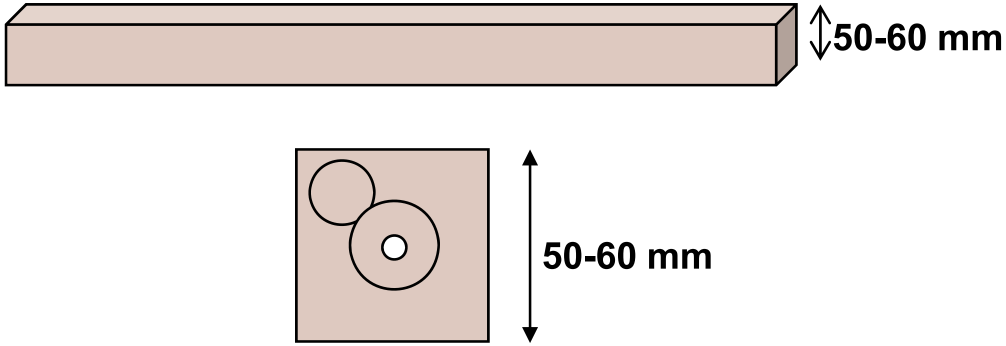
SC Synchrocyclotron
230 MeV/u
H_2^+ and C^{+6}
@ 300-400 Hz
(TERA + EPFL+ A. Laisné
and
P. Mandrillon + IBA)

This is the
« CABOTO 12 GHz » design project
proposed for a collaboration with
CLIC, EPFL, PSI

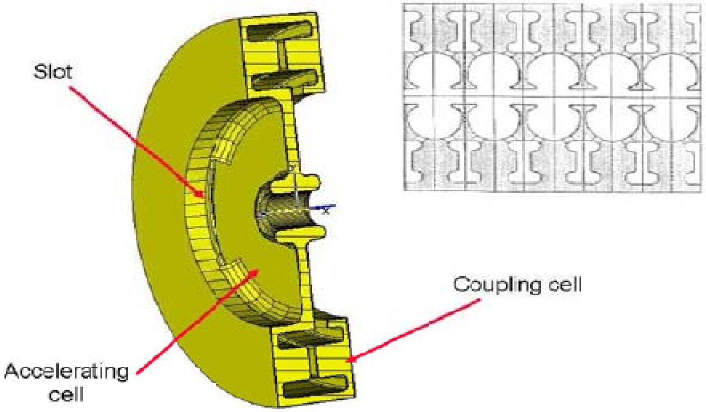
Design of two 12 GHz accelerating structures and possibly construction/tests Collaboration with the CLIC team

A. SCL
very similar to
LIGHT for IDRA





B. ACS
studied by TERA



CONCLUSION

- **Excellent progress of X-band technology for Multi-TeV linear Collider towards CLIC feasibility demonstration by 2010**

- **Addressing issues and Operational experience in Test Facilities (CTF3, SLAC, KEK, ATF, CESR-TA…)**

- **Developments towards industrial and practical applications:**
    - **Operational facilities (X-FEL…)**
    - **Medical applications (cancer therapy…)**

- **CLIC/CTF3 world-wide collaborations of 27 Institutes from 15 countries with outstanding contributions**

- **Large number of attractive opportunities for new collaborations on challenging technical developments**

- **The (present and future) contributions of present collaborators highly appreciated**

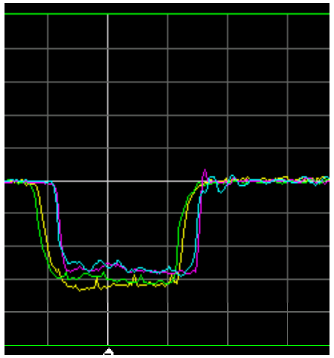
- **Extension of present contribution and additional future collaborations welcome and warmly encouraged**

SPARES

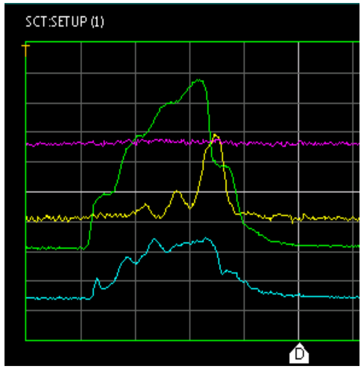
CLIC Power Extraction and Transfer Structure (PETS) high power tests at CERN (TBTS)

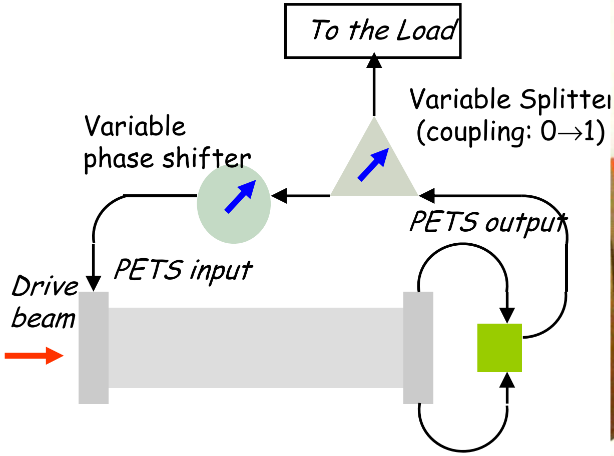
The first RF 12 GHz power generation from the PETS in re-circulation regime
17.11.2008

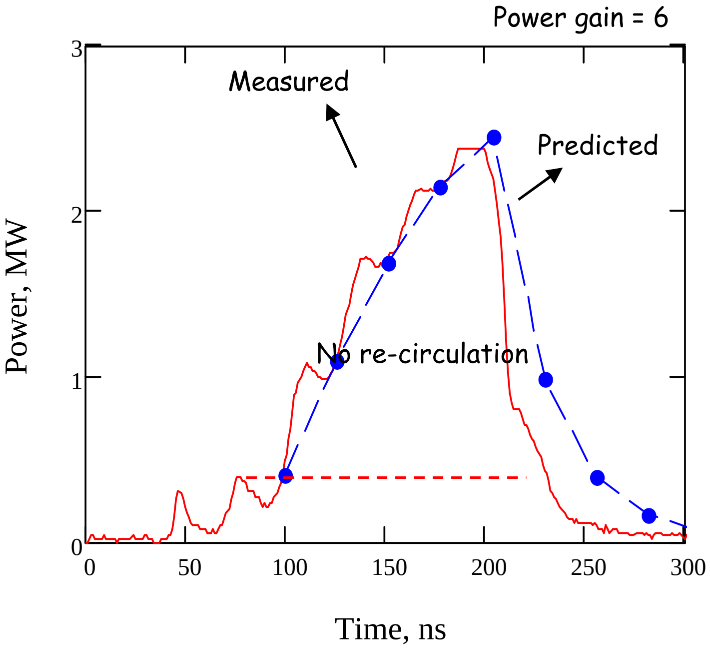
BPM signals



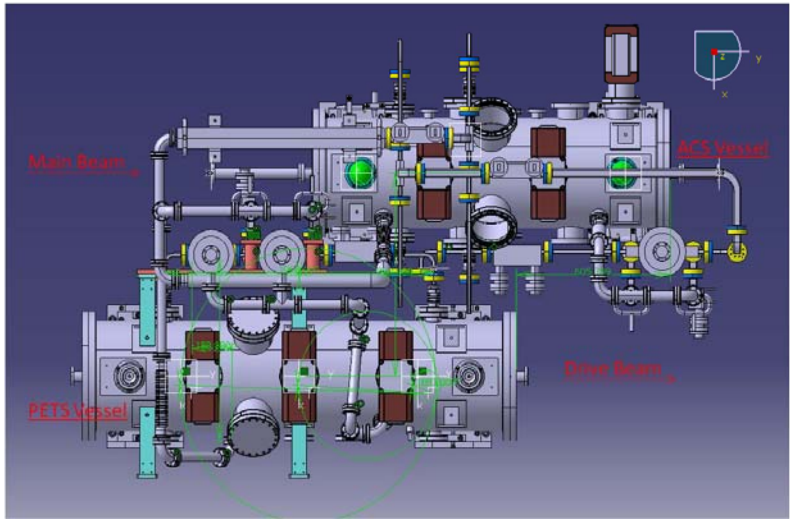
RF signals

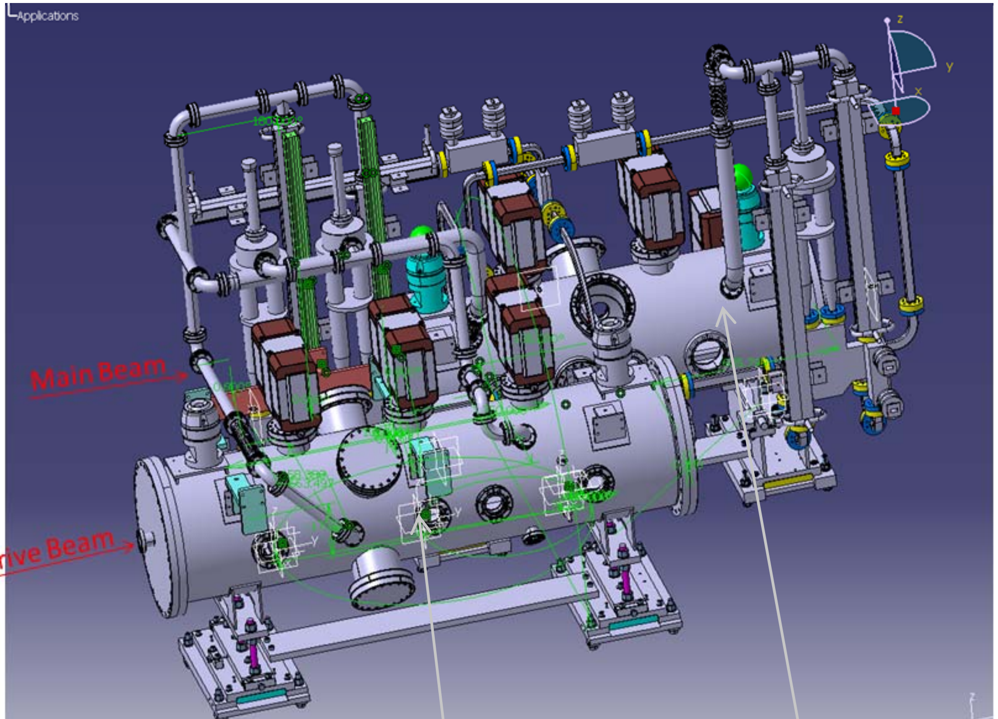


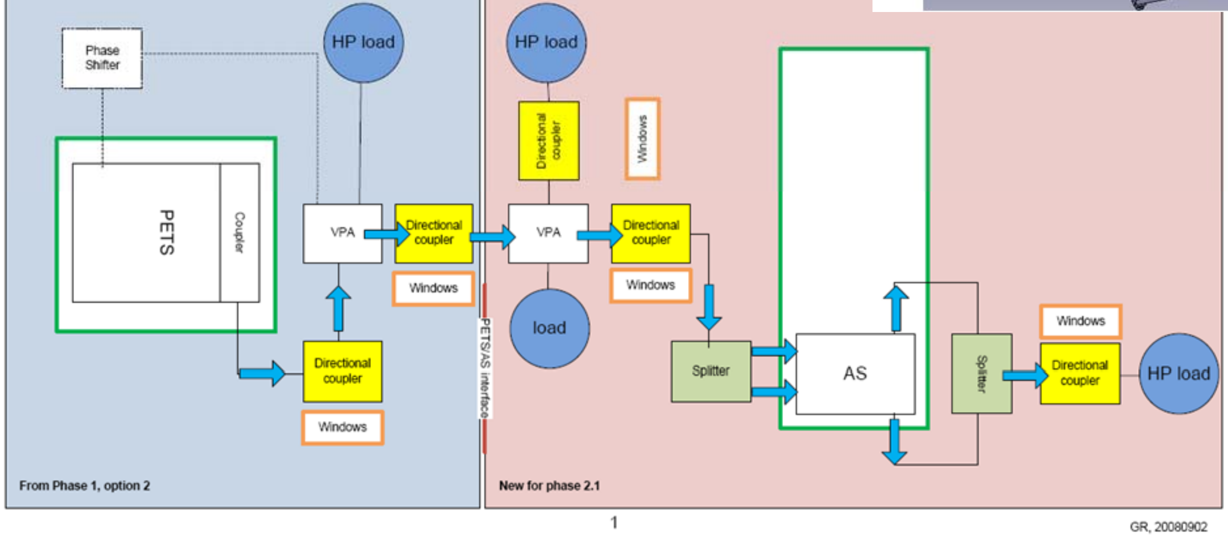




Two Beam Test Stand (TBTS) in CTF3





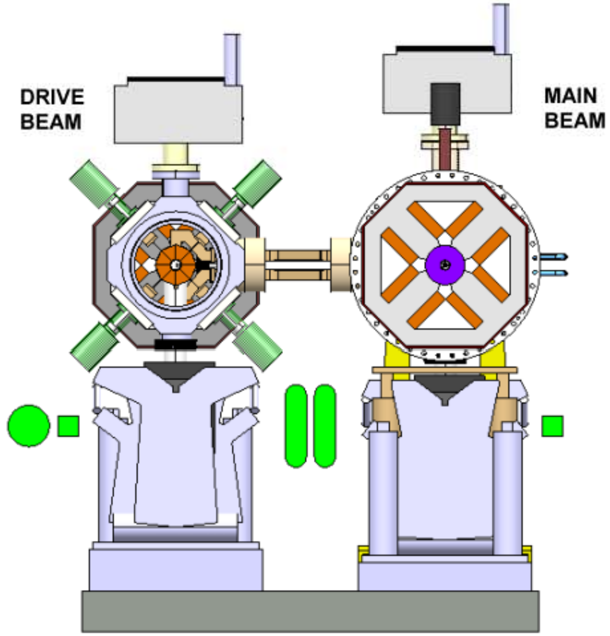


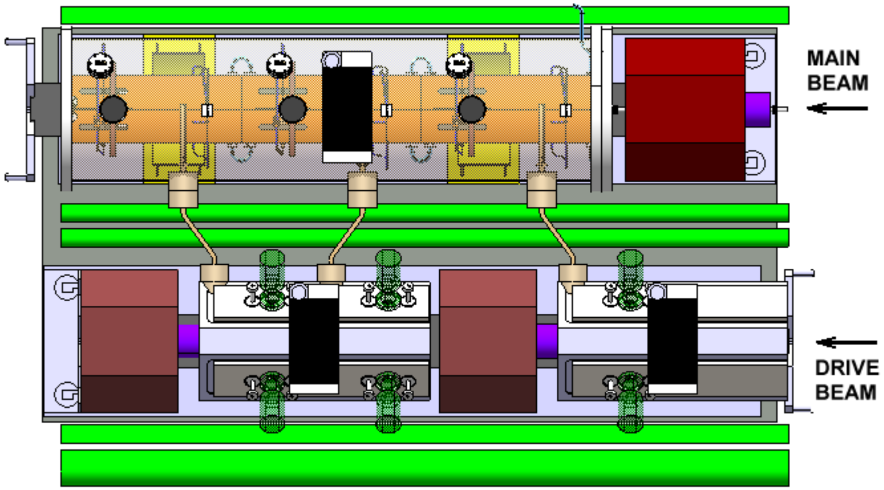
PETS

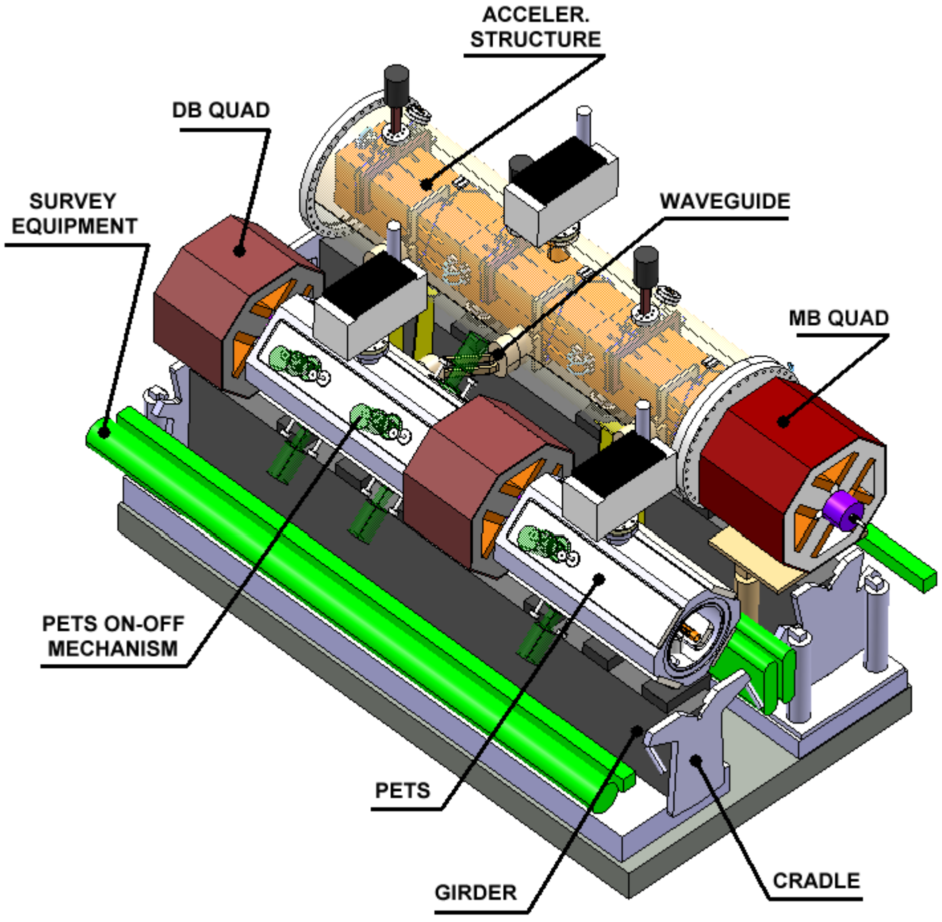
Accelerating structure

)

CLIC Standard Two Beam Module







U.S. Collaboration on High Gradient Research

- Bi-annual meetings, synchronized with “Advanced Accelerator Concepts” workshop
- Strong synergy with CLIC – good collaboration with both CERN and KEK.
- Some studies directly related to CLIC are covered by this collaboration (fabrication and test of CLIC structures, breakdown theory, source development)
- Establishes an entry point to US Labs and Universities.

Fruitful collaboration with US High Gradient Research

US collaborative effort of interested US institutes

Basic R&D on the understanding and tests of the fields limitations in warm accelerating structures

Initiated by "DOE interested in collaborating with CERN on long range accelerator and technology R&D of importance to the CLIC approach"

Laboratories (ANL, LBNL, NRL,SLAC), Universities (MIT, Maryland), Business associates,

Beyond 2010

- Work plan (2011-2015) assuming successful feasibility demonstration by 2010 :

  201006_CLIC_LTP_2006_15.doc

- Preparation of a Technical Design Report by 2015
- Addressing remaining critical issues not sufficiently demonstrated
- Is a new Test Facility needed?
- Could this facility also used for Physics?

CLIC critical issues
R&D strategy and schedule

Overall list available under: https://edms.cern.ch/document/918791

Issues classified in three categories:

- **critical for CLIC design and technology feasibility**
  - **Fully addressed by 2010 by specific R&D with results in Conceptual Design Report (CDR)**
  - **Preliminary Performance & Cost**
- **critical for performance**
- **critical for cost**
  - **Both being addressed now by specific R&D to be completed before 2015 with results in Technical Design Report (TDR)**
  - **Consolidated Performance & Cost**

X-BAND RF STRUCTURE & BEAM DYNAMICS WORKSHOP
COCKCROFT INSTITUTE
1-4 December 2008

CLIC feasibility issues

SYSTEMS (level n)		Critical parameters	Feasibility issue	Performance issue	Cost issue
Structures	<u>Main beam acceleration structures</u> Demonstrate nominal CLIC structures with damping features at the design gradient, with design pulse length and breakdown rate .	100 MV/m 240 ns 3·10-7 BR/(pulse*m)	X	X	X
	<u>Decelerator structures</u> Demonstrate nominal PETS with damping features at design power, with design pulse length, breakdown rate on/off capability	136 MW 240 ns	X		X
Drive Beam	<u>Validation of drive Beam</u> - production - phase stability , potential feedbacks - MPS appropriate for beam power	0.2 degrees phase stability at 12 GHz	X	X	
Two Beam	Test of a relevant linac sub-unit with both beams	NA	X		
Beam Physics	- Preservation of low emittances (main linac + RTML)	Absolute blow-up Hor: 160nradm Vert: 15 nradm	X	X	
Stabilization	Main Linac and BDS Stabilization	Main Linac : 1 nm vert (>1 Hz) BDS: 0.15…1 nm vert (>4 Hz) depending on implementation of final doublet girder	X	X	X
Operation and reliability	Commissioning strategy Staging of commissioning and construction MTBF, MTTR Machine protection	Handling of drive beam power of 72 MW	X	X	X

EuCARD – man-power estimate (person-months)

NCLINAC

Beneficiary no./Short name	WP 1	WP 2	WP 3	WP 4	WP 5	WP 6	WP 7	WP 8	WP 9	WP 10	WP 11	Total person months
1 CERN	84	10	21.6	11	3		116	84	88.4	38	32	488
2 ARC								4				4
3 BESSY										10		10
4 BINP											24.5	24.5
5 CEA							139			85.5		224.5
6 CIEMAT									32			32
7 CNRS				4.5			28		50.4	50.5	46.4	179.8
8 COLUMBUS							4					4
9 CSIC								18				18
10 DESY				3.6			11			88		102.6
11 BHTS							4					4
12 EPFL								8.4				8.4
13 FZD										16		16
14 FZK							16					16
15 GSI								116				116
16 IFJ PAN										8		8
17 INFN			3.6				18	24	30.4	18	110	204
18 IPJ										26		26
19 POLITO								14				14
20 PSI									15			15
21 PWR							49					49
22 RHUL									53			53
23 RRC KI								35				35
24 SOTON							7					7
25 STFC						3	36		16	18	46	119
26 TUL										38		38
27 TUT							8					8
28 UH									112			112
29 UJF				5.6								5.6
30 ULANC										42.5		42.5
31 UM								12				12
32 UNIGE			20.6				10					30.6
33 UNIMAN									75	45		120
34 UOXF-DL									53			53
35 UROS										24		24
36 UU									68			68
37 WUT		14								22		36
Grand Total	84	24	45.8	24.7	3	3	446	315.4	593.2	529.5	258.9	2327.5

EuCARD – budget distribution:

WP no.	Activity	WP short title	Total cost (k€)	EC request (k€)
1	MGT	**Project Management**	831	22
2	NA	**DCO**	273	137
3	NA	**NEU2012**	548	278
4	NA	**AccNet**	998	594
5	TA	**HiRadMat@SPS**	941	59
6	TA	**MICE**	1,635	222
7	RTD	**HFM**	6,438	2,057
8	RTD	**ColMat**	4,090	1,279
9	RTD	**NCLinac**	6,551	2,001
10	RTD	**SRF**	7,730	2,416
11	RTD	**ANAC**	3,018	0,934
Total (k€)			**33,053**	**10,000**

Relative cost of Linear Colliders