Towards CLIC feasibility

J.P.Delahaye for the CLIC collaboration

- **Update from last presentation in Nov 2009**
- **Progress of R&D on CLIC feasibility issues**
- **Preparation of Conceptual Design Report**
- **Conclusion**

CLIC multi-lateral Collaboration

38 volunteer Institutes from 19 Countries

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

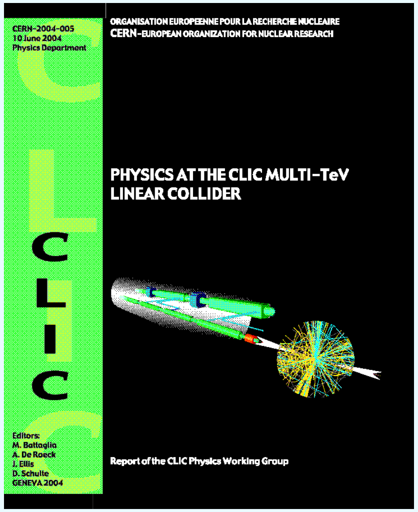
4 Additional Members

- **ETHZ/ Switzerland:**
  - Alignment R&D
- **IHEP/China:**
  - X-band RF components developments (design and construction)
- **JAI (Oxford)/UK:**
  - Beam instrumentation and diagnostics
- **UCSC-SCIPP/USA:**
  - LC detector R&D

THE COMPACT LINEAR COLLIDER (CLIC) STUDY

Objective: site independent study exploring possible extension of e^+/e^- linear colliders into the Multi-TeV colliding beam energy range by developing most appropriate technology :

- ✓ E_{CM} energy range complementary to LHC => E_{CM} = 0.5- 3 TeV
- ✓ L > few 10^{34} cm^{-2} with acceptable background & energy spread
- ✓ Affordable cost and power consumption



Physics motivation:

- ✓ Consensus supported by ICFA of Lepton Collider (precision) favored facility to complement the LHC (discovery) in future
- ✓ "Physics at the CLIC Multi-TeV Linear Collider: http://clicphysics.web.cern.ch/CLICphysics/

Present goals:

R&D addressing Feasibility Issues

Conceptual Design (Accelerator & Detector) with preliminary performance & cost estimations

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

10 CLIC Feasibility Issues

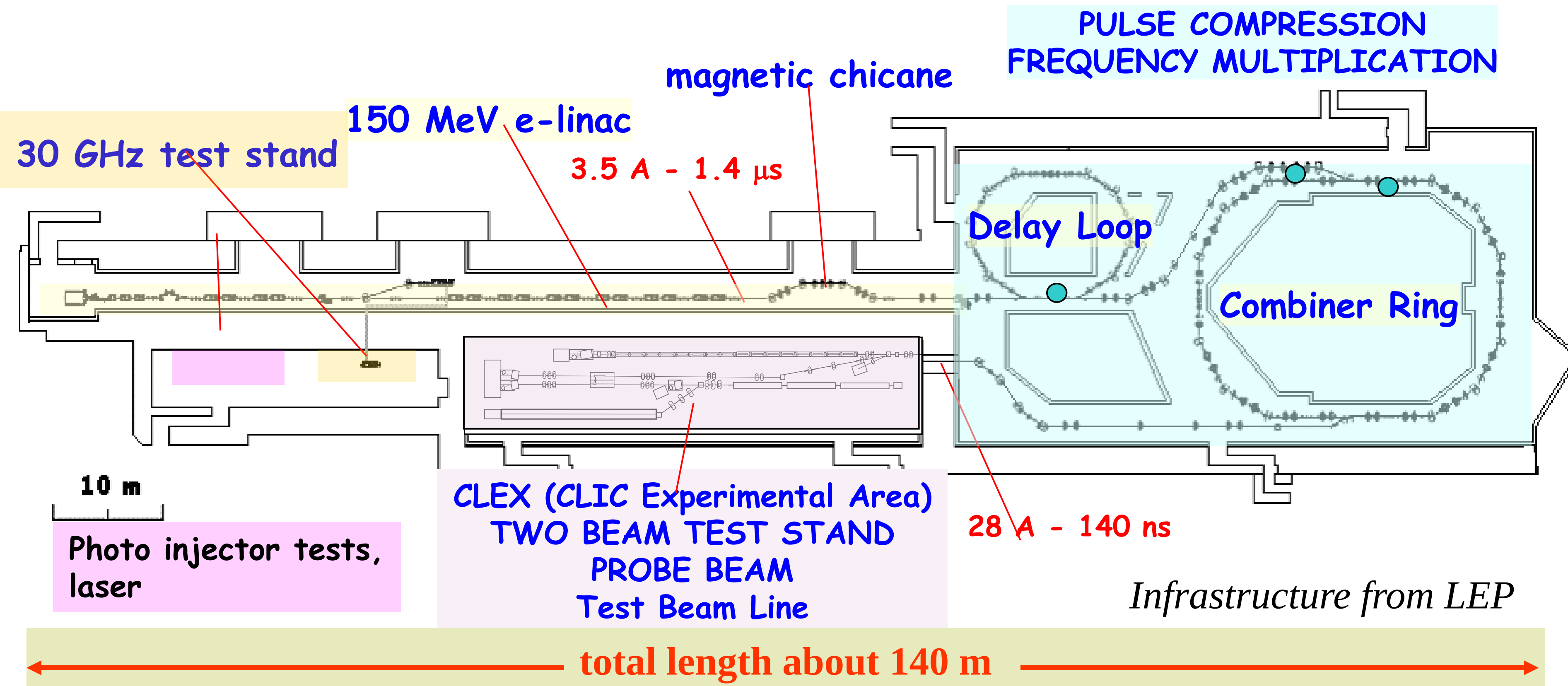
- **Two Beam Acceleration:**
  - Drive beam generation
  - Beam Driven RF power generation
  - Two Beam Module
- **RF Structures:**
  - Accelerating Structures (CAS)
  - Power Production Structures (PETS)
- **Ultra low beam emittance and beam sizes**
  - Emittance generation & preservation during acceleration and focusing
  - Alignment and stabilisation
- **Detector**
  - Adaptation to short interval between bunches
  - Adaptation to large background at high beam collision energy
- **Operation and Machine Protection System (MPS)**

CLIC feasibility issues

System	Item	Feasibility Issue	Unit	Nominal
Two Beam Acceleration	Drive beam generation	Fully loaded accel effic	%	96
		Freq&Current multipl	-	2*3*4
		12 GHz beam current	A	4.5*24=100
		12 GHz pulse length	nsec	170
		Intensity stability	1.E-03	0.75
		Timing stability	psec	0.05
	Beam Driven RF power generation	PETS RF Power	MW	130
		PETS Pulse length	ns	170
		PETS Breakdown rate	/m	< 1·10-7
		PETS ON/OFF	-	@ 50Hz
		Drive beam to RF efficiency	%	90%
		RF pulse shape control	%	< 0.1%
	Accelerating Structures (CAS)	Structure Acc field	MV/m	100
		Structure Pulse length	ns	240
		Structure Breakdown rate	/m MV/m.ns	< 3·10-7
	Two Beam Acceleration	Power producton and probe beam acceleration in Two beam module	MV/m - ns MeV	100 - 240 100/m
		Drive to main beams timing stability	psec	0.07
Ultra low beam emittances & sizes	Ultra low Emittances	Emitttance generation (H/V)	nm	550/5
		Emittance preservation: Blow-up H/V	nm	160/15
		Beam sizes at IP (H/V)	nm	40/1
	Alignment	Main Linac components	microns	15
		Final-Doublet	microns	8
	Vertical stabilisation	Quad Main Linac	nm>1 Hz	1.5
		Final Doublet (assuming feedbacks)	nm>4 Hz	0.2
Operation and Machine Protection System (MPS)		Drive Beam Power @ 2.4GeV	MW	24*3
		Main Beam Power @ 1.5TeV	MW	14

Addressing all major CLIC technology key issues in CLIC Test Facility (CTF3)

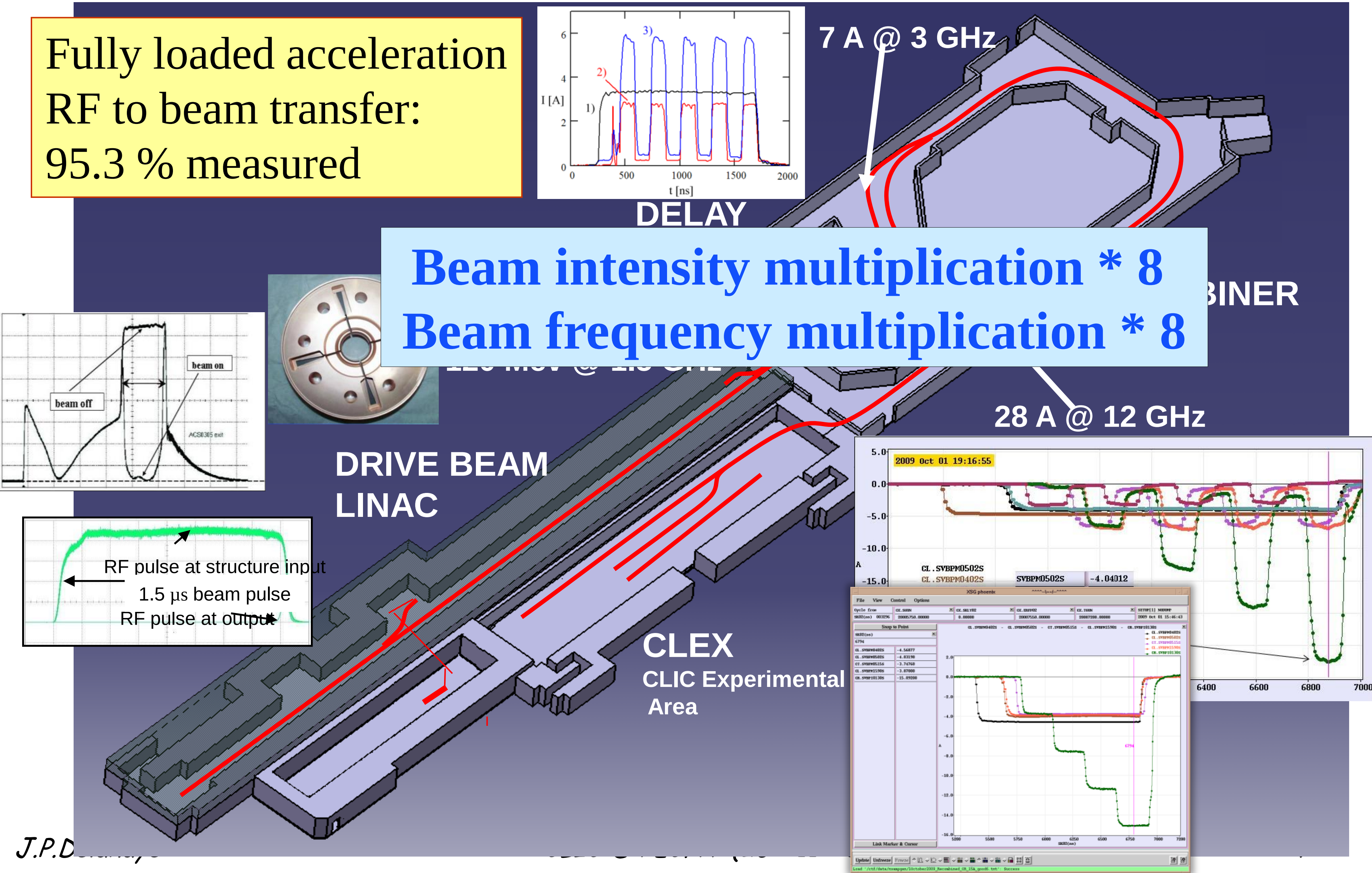
- Demonstrate Drive Beam generation
  (fully loaded acceleration, beam intensity and bunch frequency multiplication x8)
- Demonstrate RF Power Production and test Power Structures
- Demonstrate Two Beam Acceleration and test Accelerating Structures



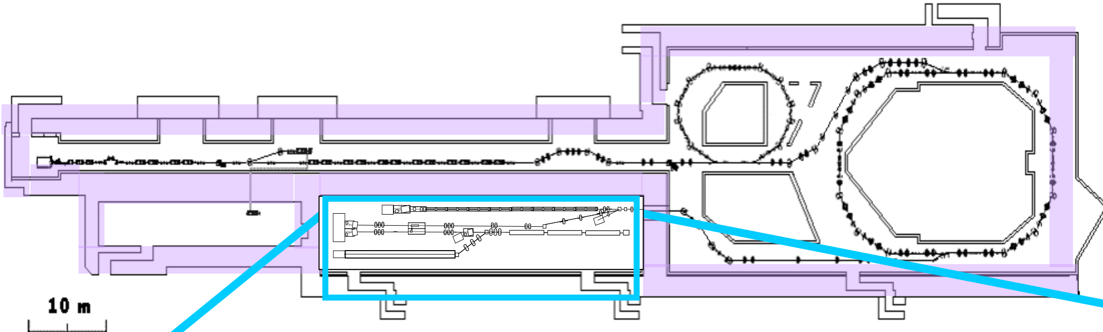
CTF3 completed, operating 10 months/year, under commissioning: Drive Beam Generation demonstrated

Fully loaded acceleration RF to beam transfer: 95.3 % measured

Beam intensity multiplication * 8
Beam frequency multiplication * 8



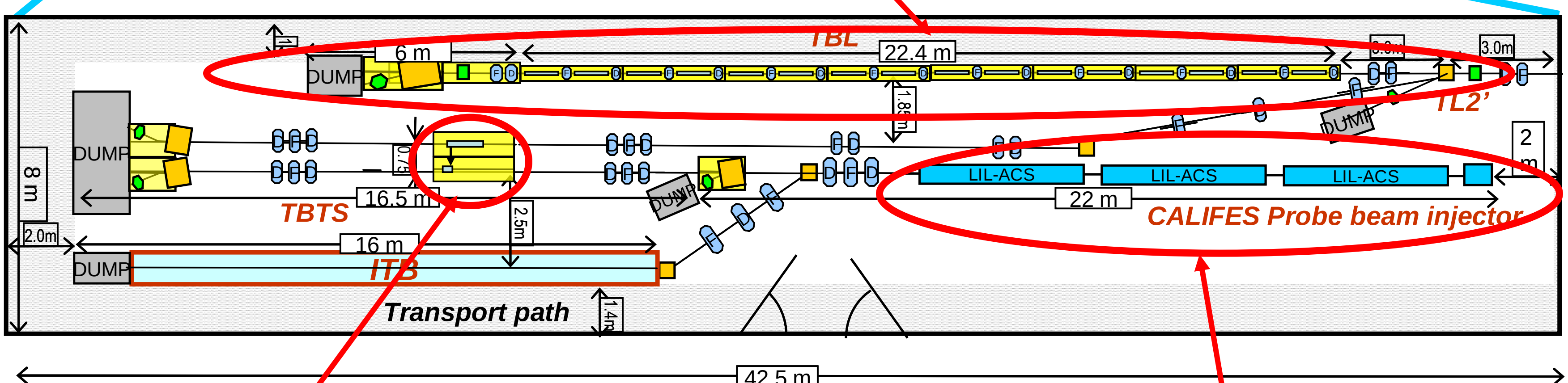
CTF3/CLEX (CLIC Experimental Area)



Test beam line (TBL) to study RF power production (1.5 TW at 12 GHz) and drive beam decelerator dynamics, stability & losses

- Two Beam Test Stand to study probe beam acceleration with high fields at high frequency and the feasibility of Two Beam modules

Test Beam Line TBL



Two Beam Test Stand

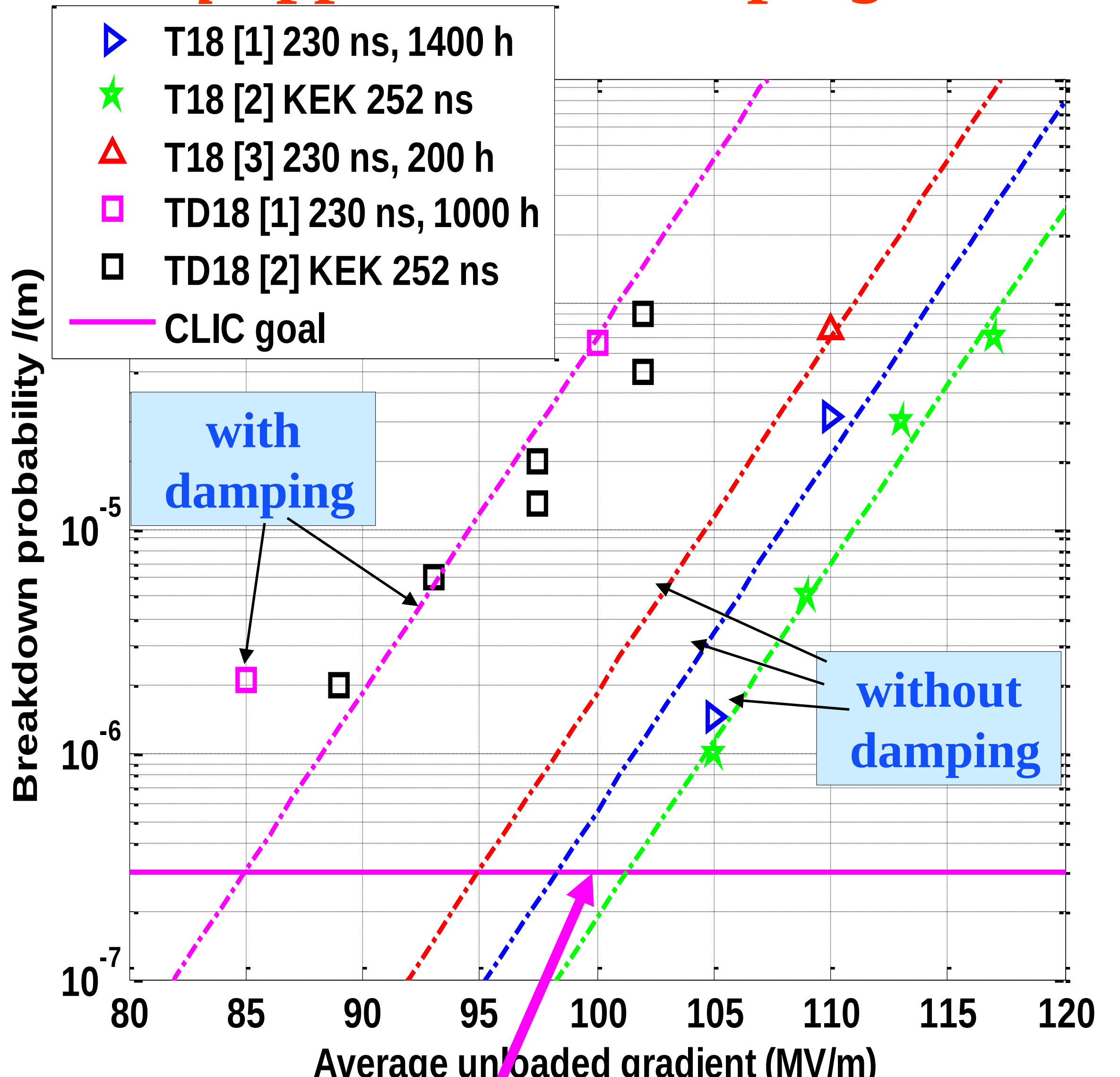
Probe Beam

Installation completed except for PETS in TBL

Drive and probe beams in CLEX from June 2008

Progress on tests of Accelerating Structures equipped with Damping Slots

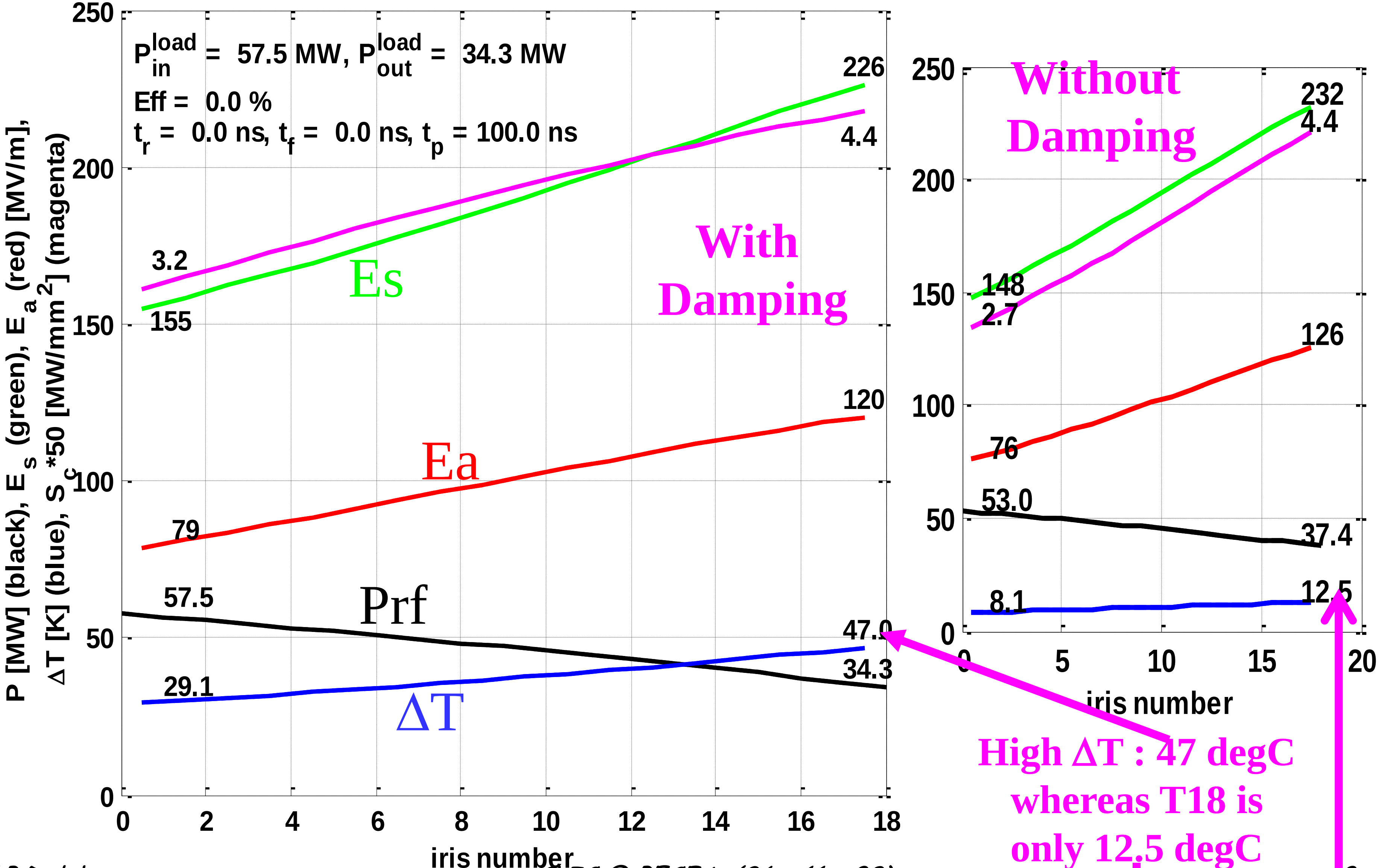
- 3 structures no damping: Exceeded 100 MV/m at nominal breakdown rate
- 2 structures with damping slots: Exceeded 100 MV/m at larger breakdown rate
- Low statistics, high reprod.
- 25% reduction of perform. by Damping Slot
- Effect attributed to excessive RF pulse heating
- Nominal structure (TD24) with reduced RF pulse heating under tests



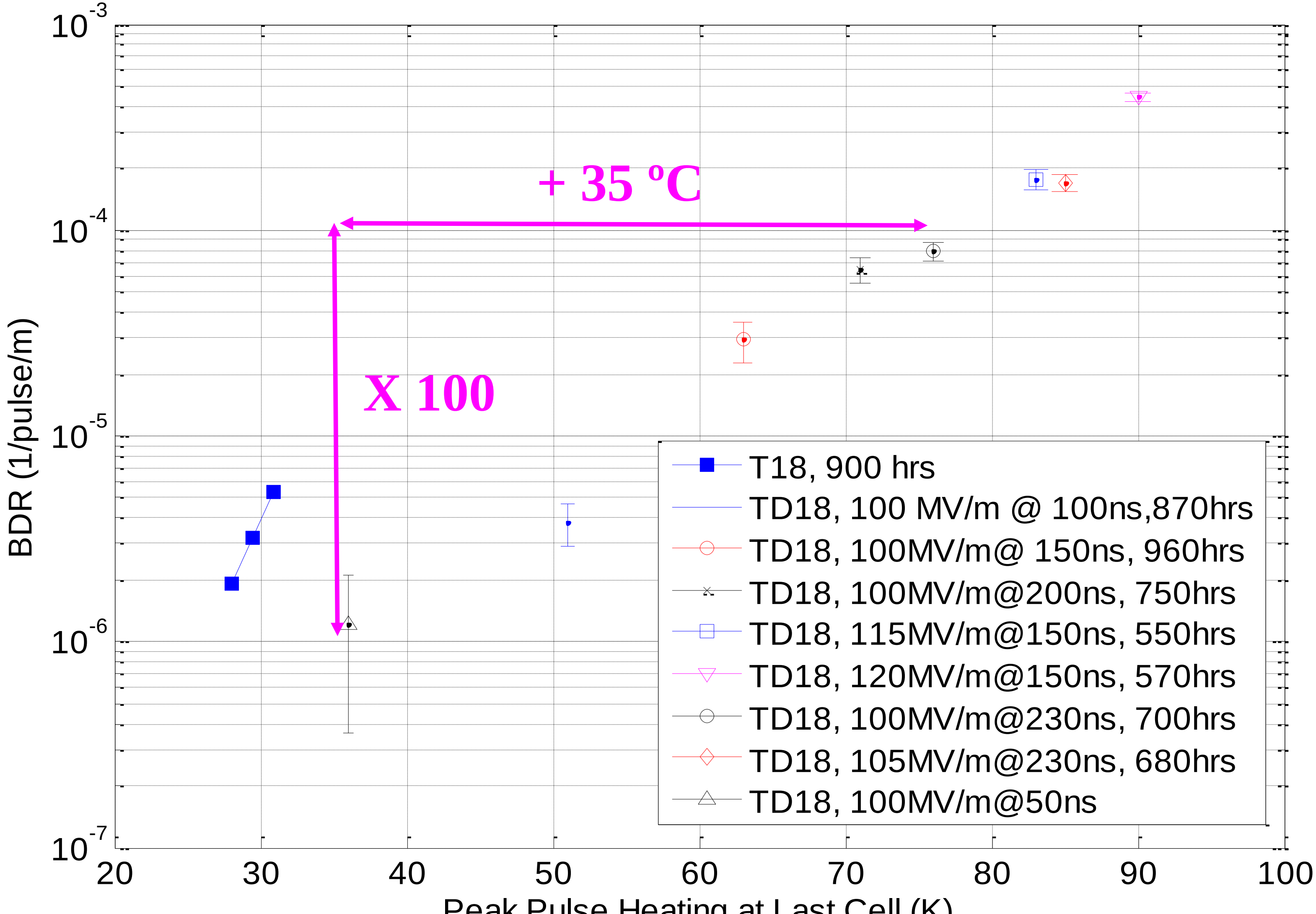
CLIC goal: 100 MV/m loaded with BR<3 10-7/m

J.P.Delahaye

Fields and RF pulse heating along the Accelerating Structure

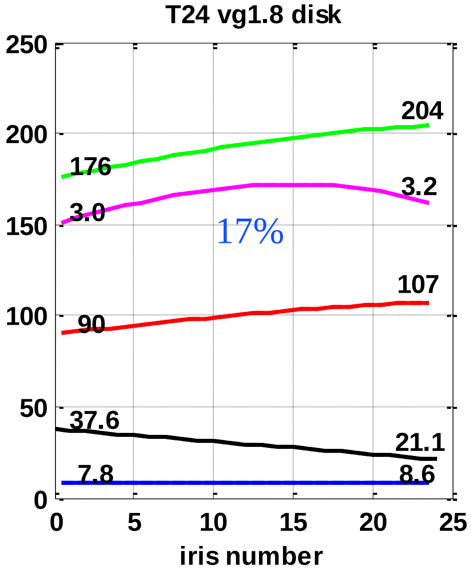


Breakdown rate versus RF pulsed heating

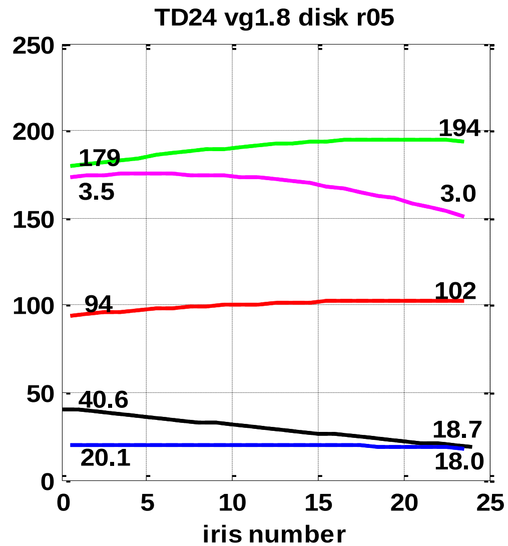


RF pulse heating mitigation in nominal CLIC accelerating structure (TD24)

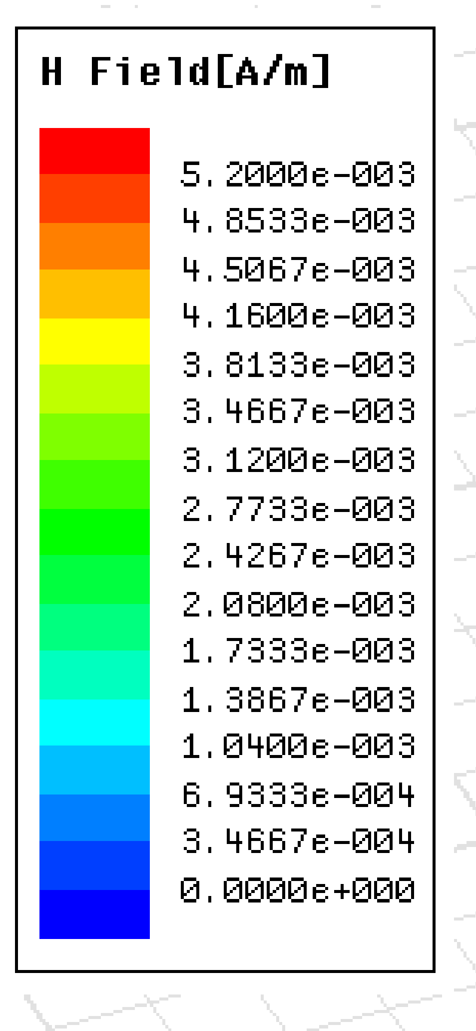
Without Damping

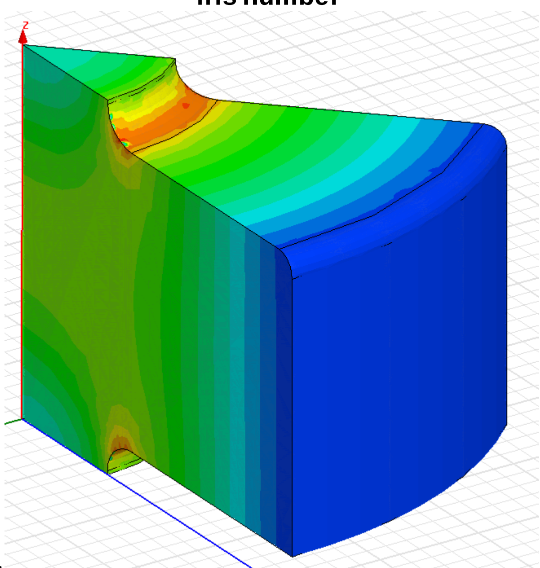


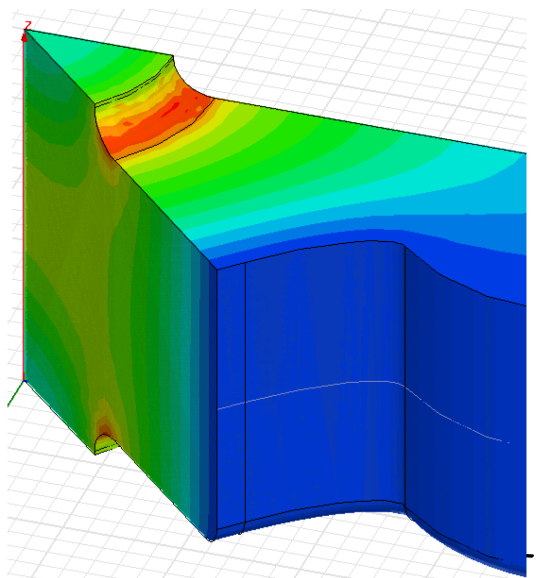
With Damping



Surface magnetic field after RF design optimisation





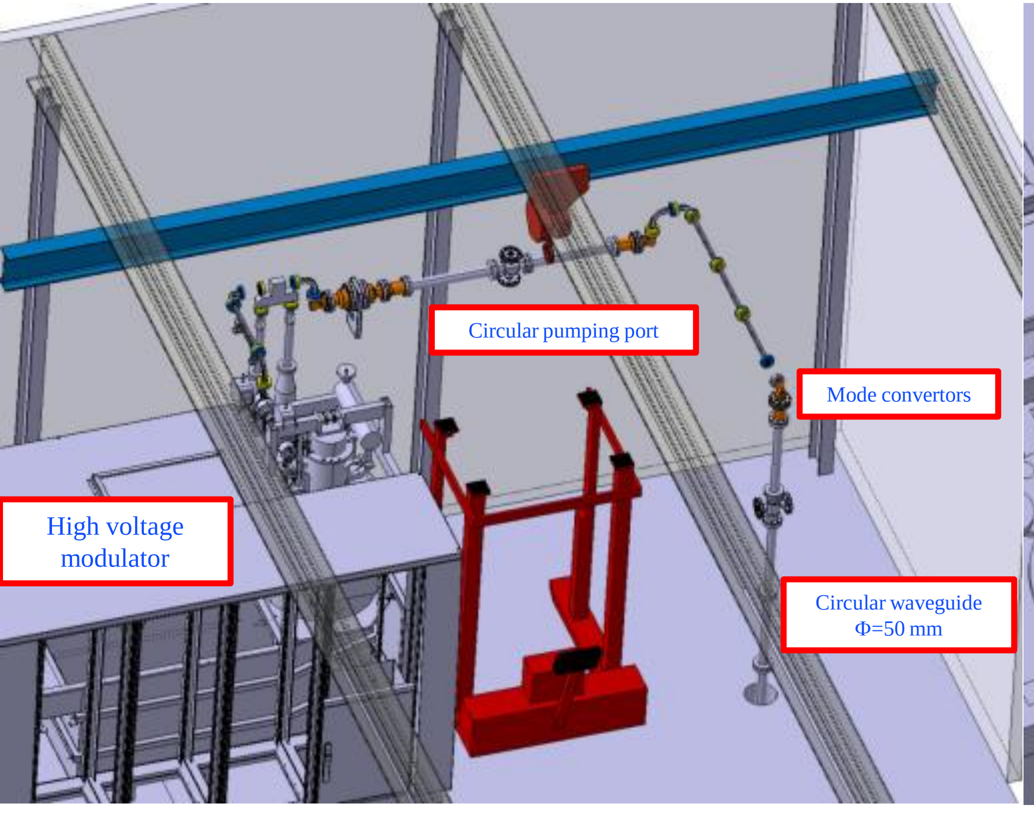


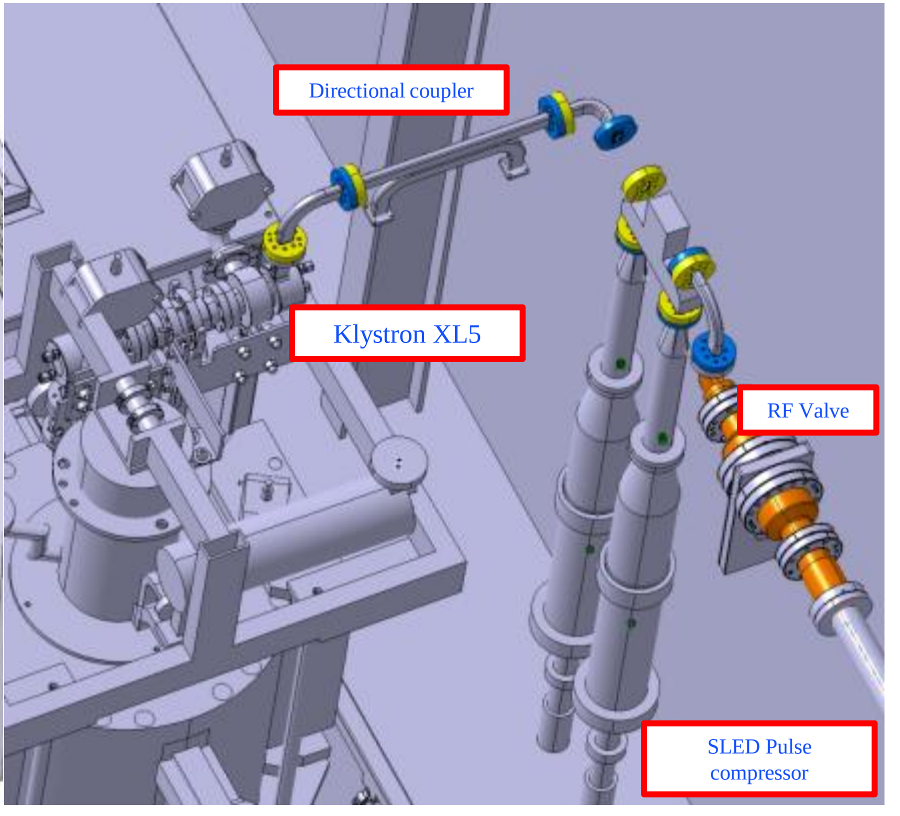
RF structures tests schedule

28.4.2010		2010											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dez
Facility	Structure												
SLAC NLCTA	TD18_vg2.4_disk[3]												
11.4 GHz	T24vg1.7_disk [3]												
	TD24vg1.7_disk [3]												
	T18_vg2.4_disk[3]												
	T18_vg2.4_disk[6]_CERN												
	TD24 KS CERN												
SLAC ASTA	PETS 11.4 GHz												
	C10vg0.7[1]												
	PETS 11.4 GHz_ SiC												
KEK NEXTEF													
	TD18_vg2.4_disk[2]												
	T24vg1.7_disk [4]												
	TD24vg1.7_disk [4]												
CERN Test Stand	T24_vg1.7_disk [2]												
12 GHz	TD24_vg1.7_disk [2]												
CLEX 12 GHz													
	Pets 12 GHz												
	TD24_vg1.7_disk [1]												

CERN/CLIC X-band Test-Stand (Under Construction)

CERN - CEA – PSI – SLAC

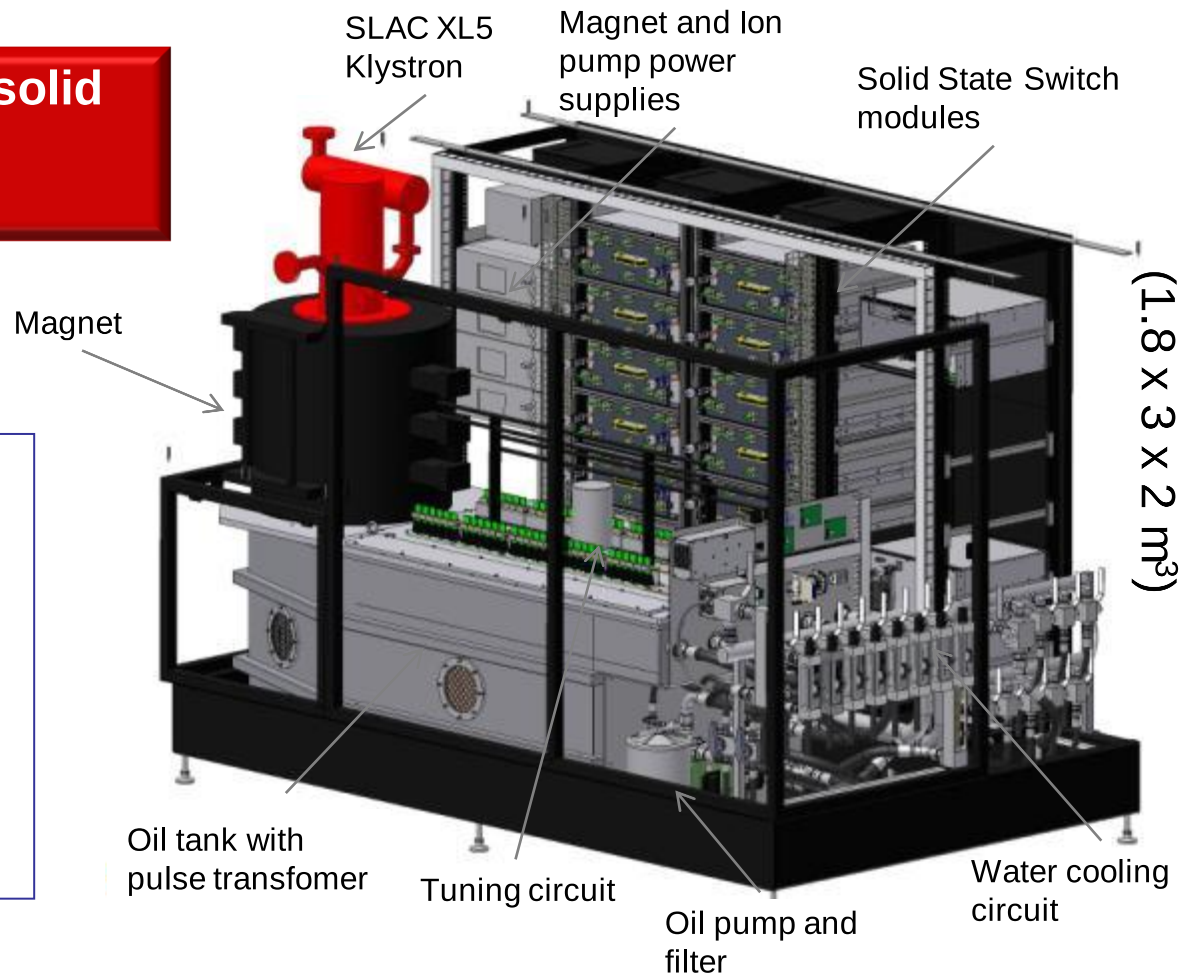


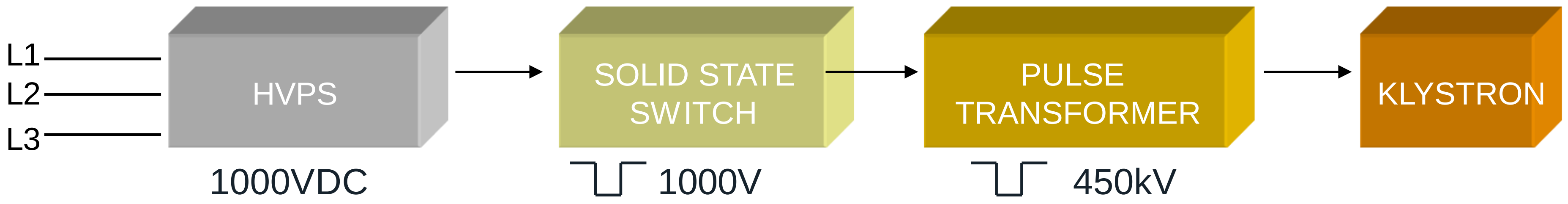


High Voltage Modulator

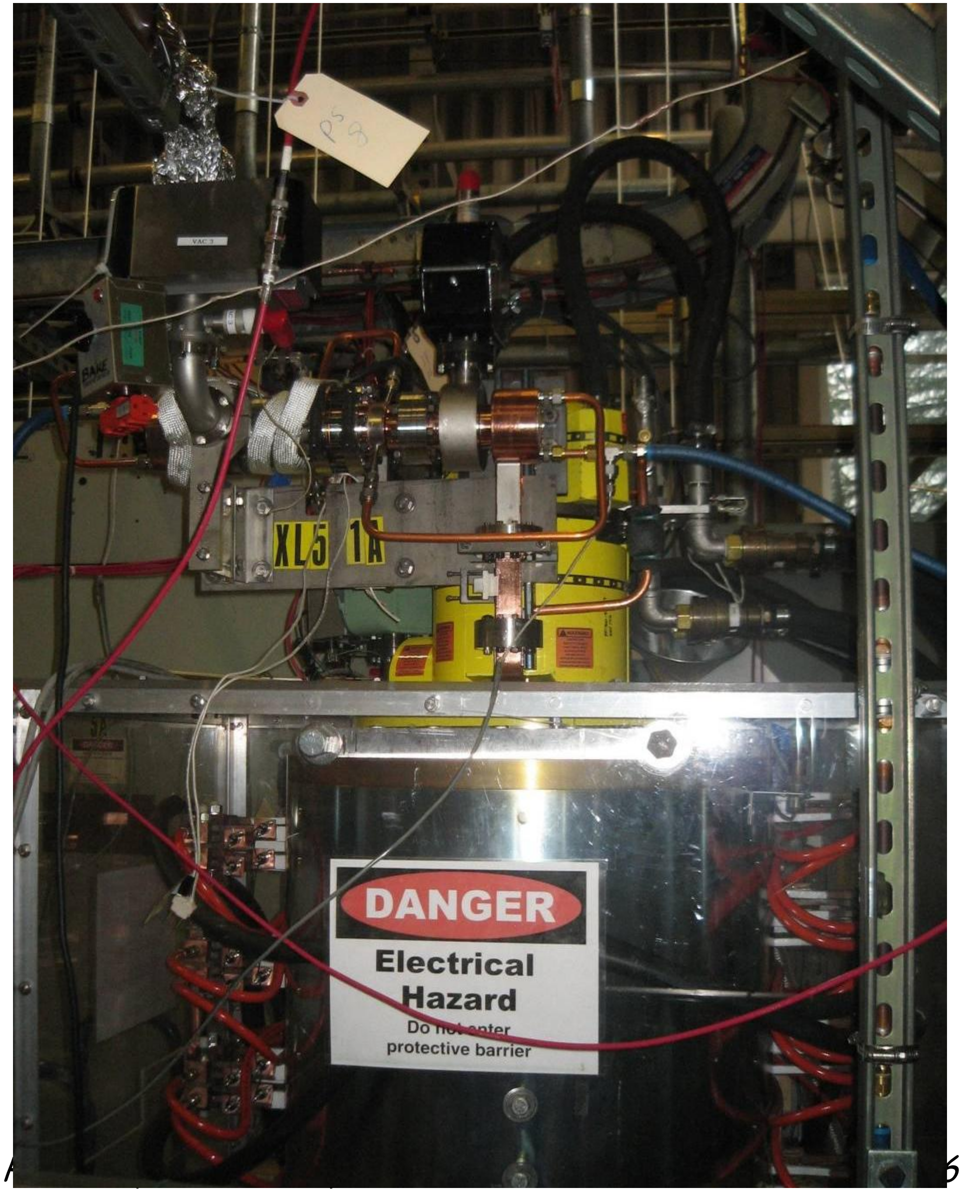
Development of a new solid state modulator by SCANDINOVA

Specification :	
High Voltage :	450 kV
Current :	335 A
Flat pulse length:	1.5 μs
Pulse length at 50%:	2.3 μs
Repetition rate:	50 Hz
HV ripple:	0.25 %
Pulse to pulse stability:	0.1 %



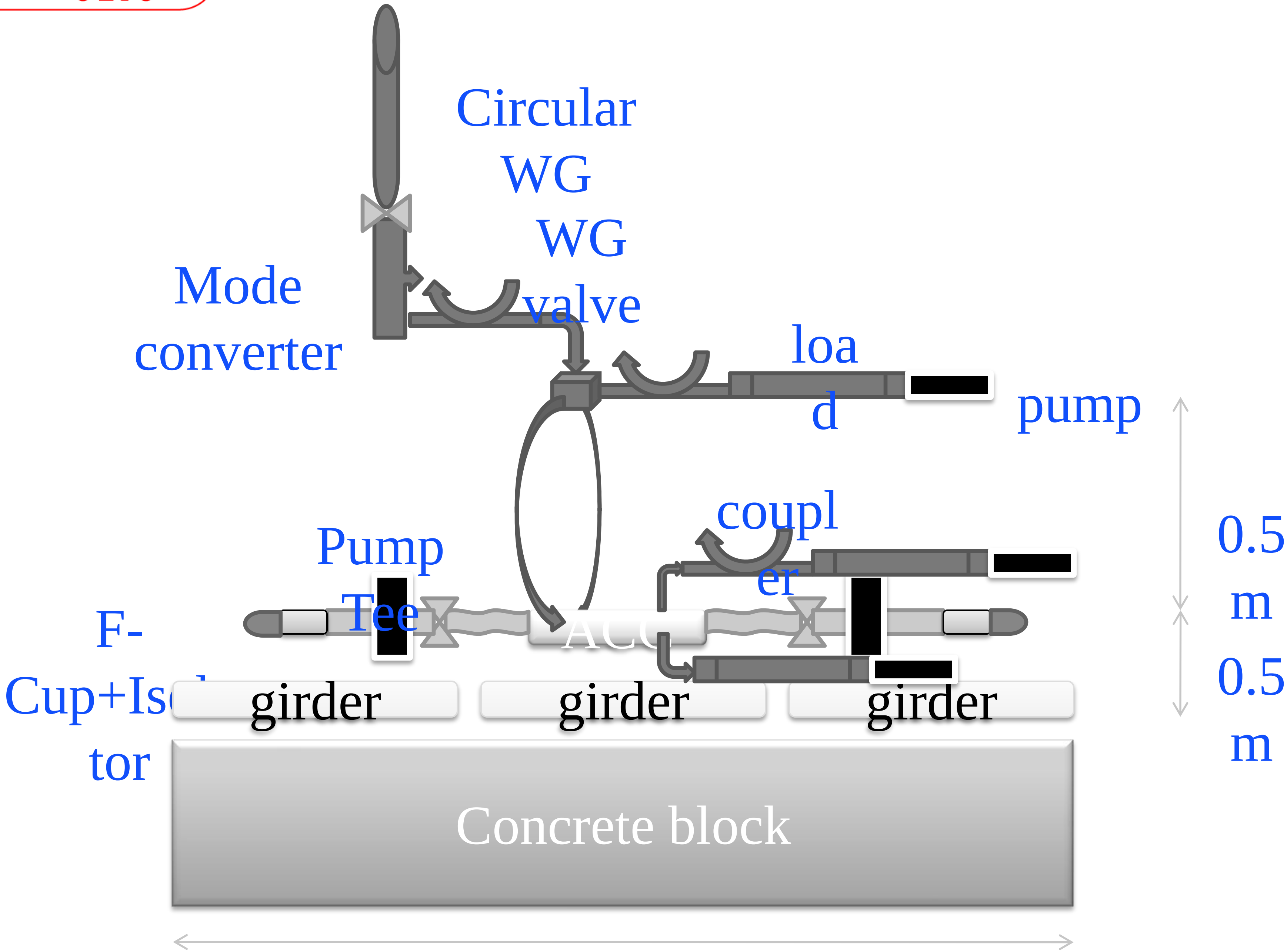


12 GHz 50 MW Klystron
SLAC XL5 (derived from NLC)

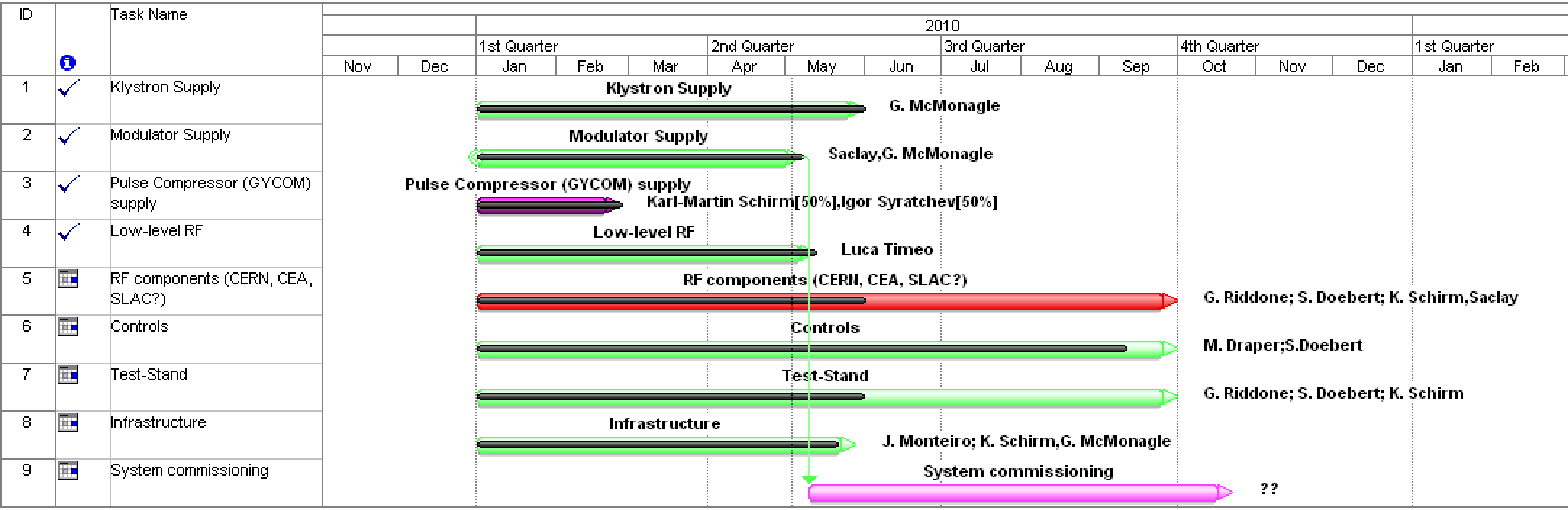


RF Pulse Compressor (Gycom)

Stand alone Test Stand in CTFII



Schedule (05/2010)



! Klystron and Modulator scheduled to arrive at CERN!

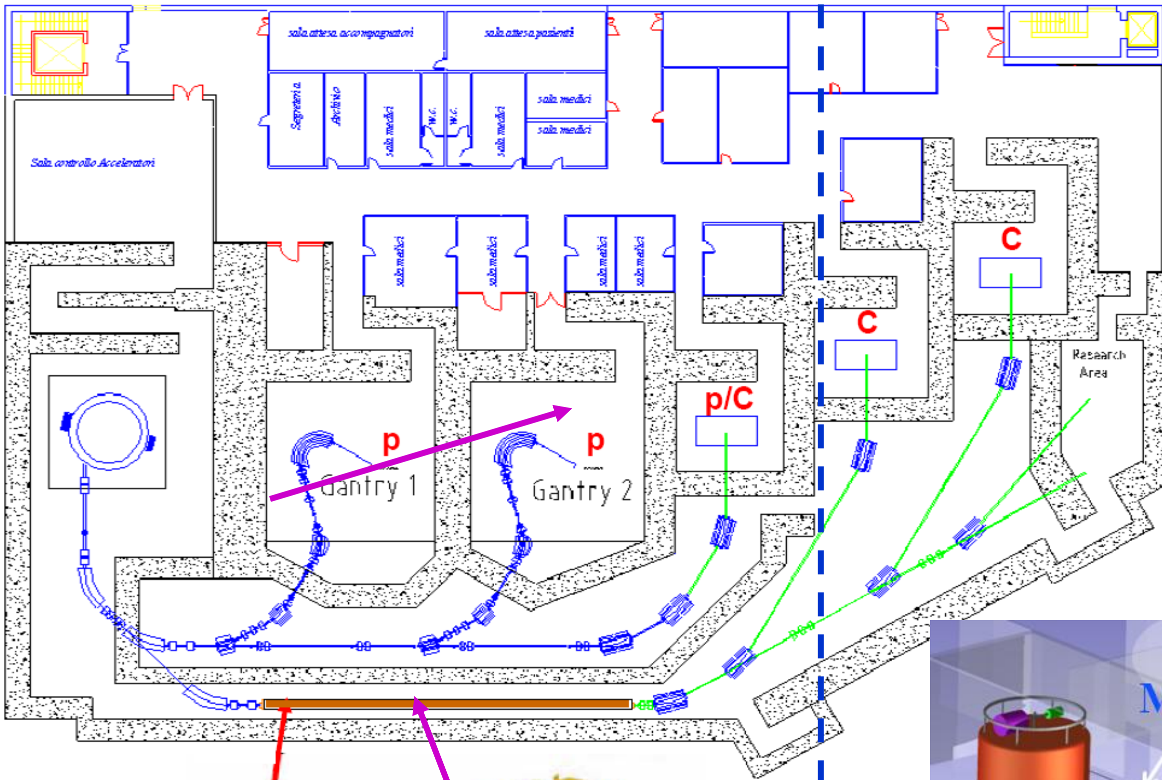
!RF components and network require new strategy and more efforts!

! 12 GHz power (without compression) available in July 2010!

Applications of X band accelerating structures:

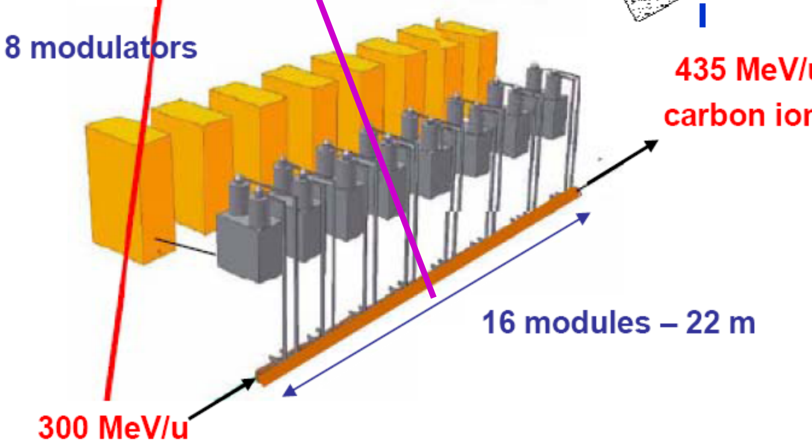
CArbon BOoster Therapy in Oncology (TERA)

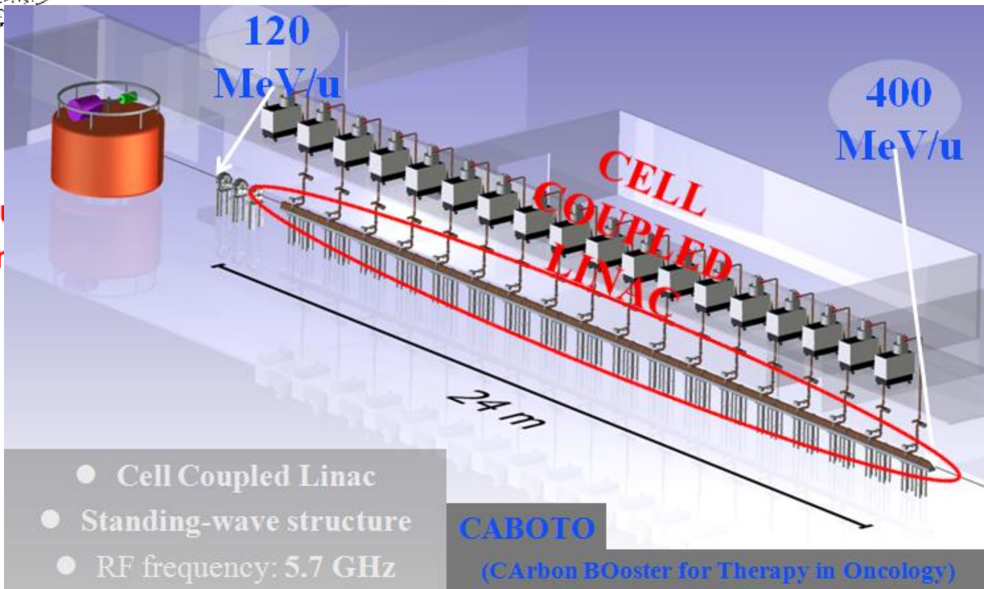
PSI/X-FEL, ELETTRA, SLAC Linac based X-FEL



TERA

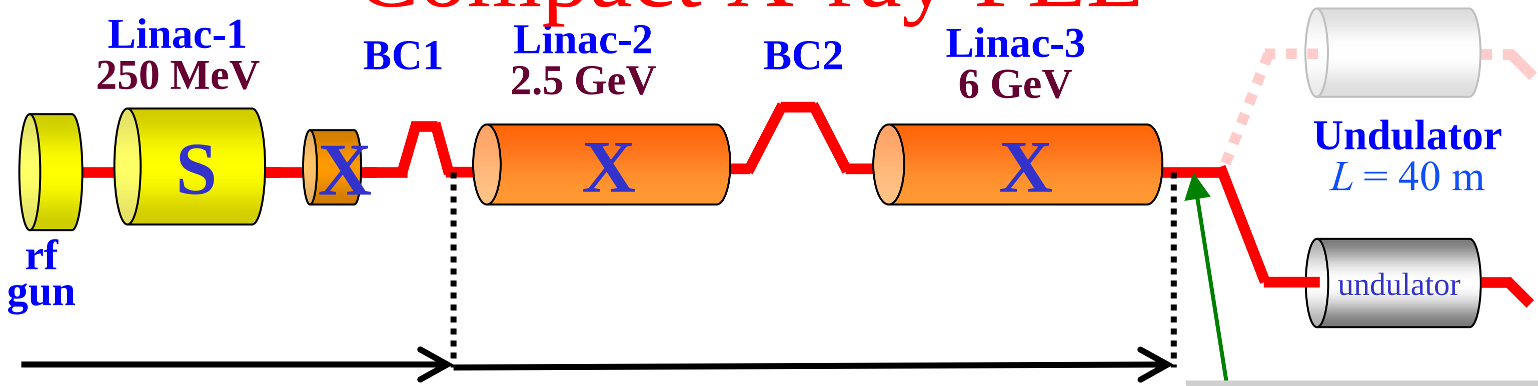
12 or 5.7 GHz
NC Linac
(power efficiency)





X-band Linac Driven Compact X-ray FEL

Courtesy C.Adolphsen/SLAC

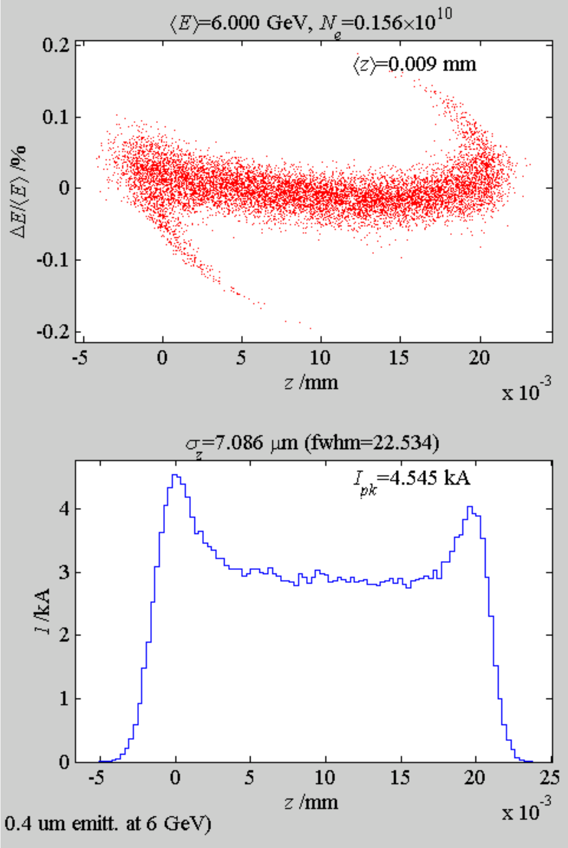


LCLS-like injector
L ~ 50 m

X-band main linac+BC2
G ~ 70 MV/m, L ~ 150 m

250 pC, $\gamma\varepsilon_{x,y} \approx 0.4\ \mu m$

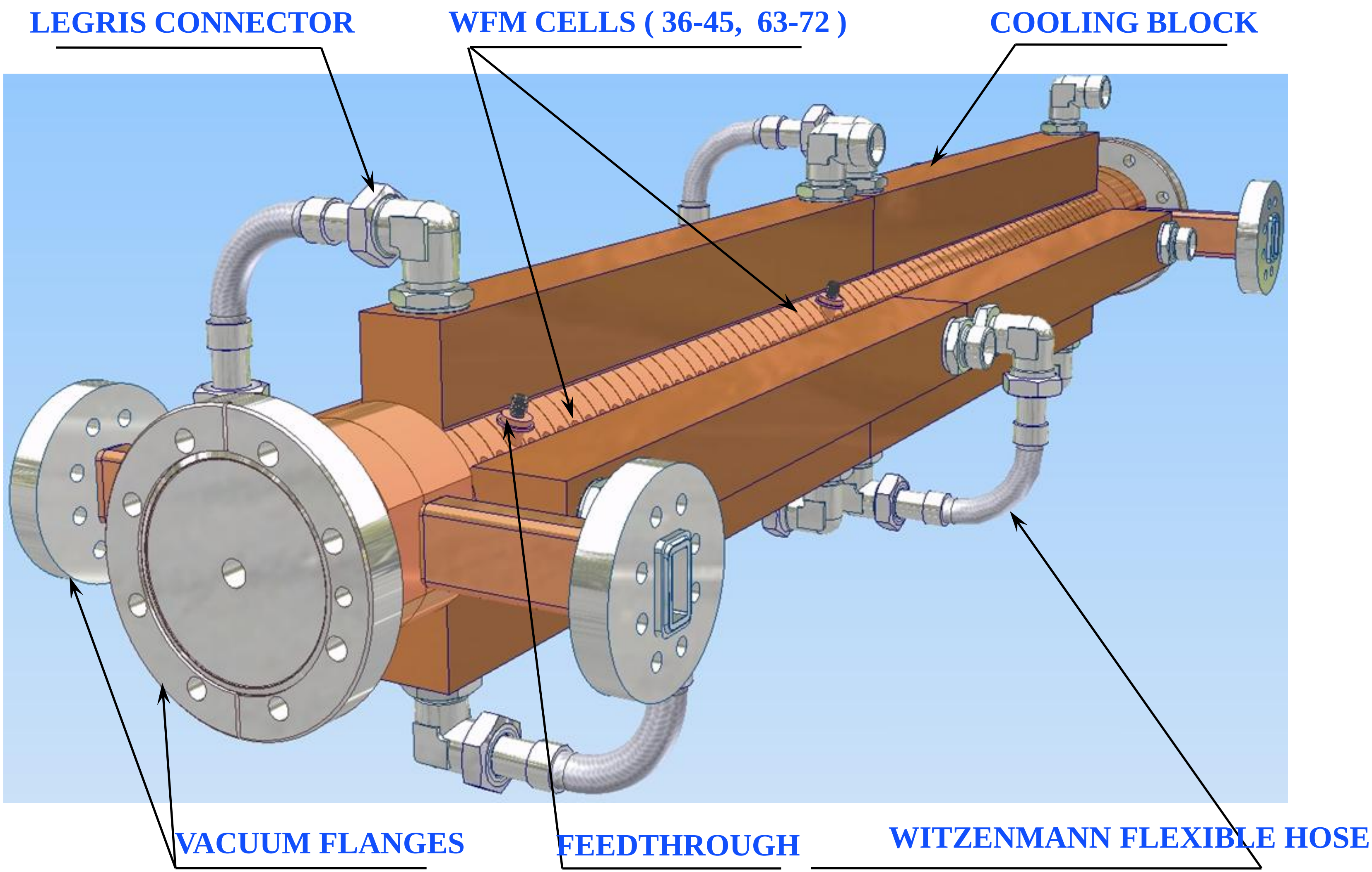
- Use LCLS injector beam distribution and H60 structure (a/λ=0.18) after BC1
- LiTrack simulates longitudinal dynamics with wake and obtains 3 kA "uniform" distribution
- Similar results for T53 structure (a/λ=0.13) with 200 pC charge



Compact X-Ray (1.5 Å) FEL

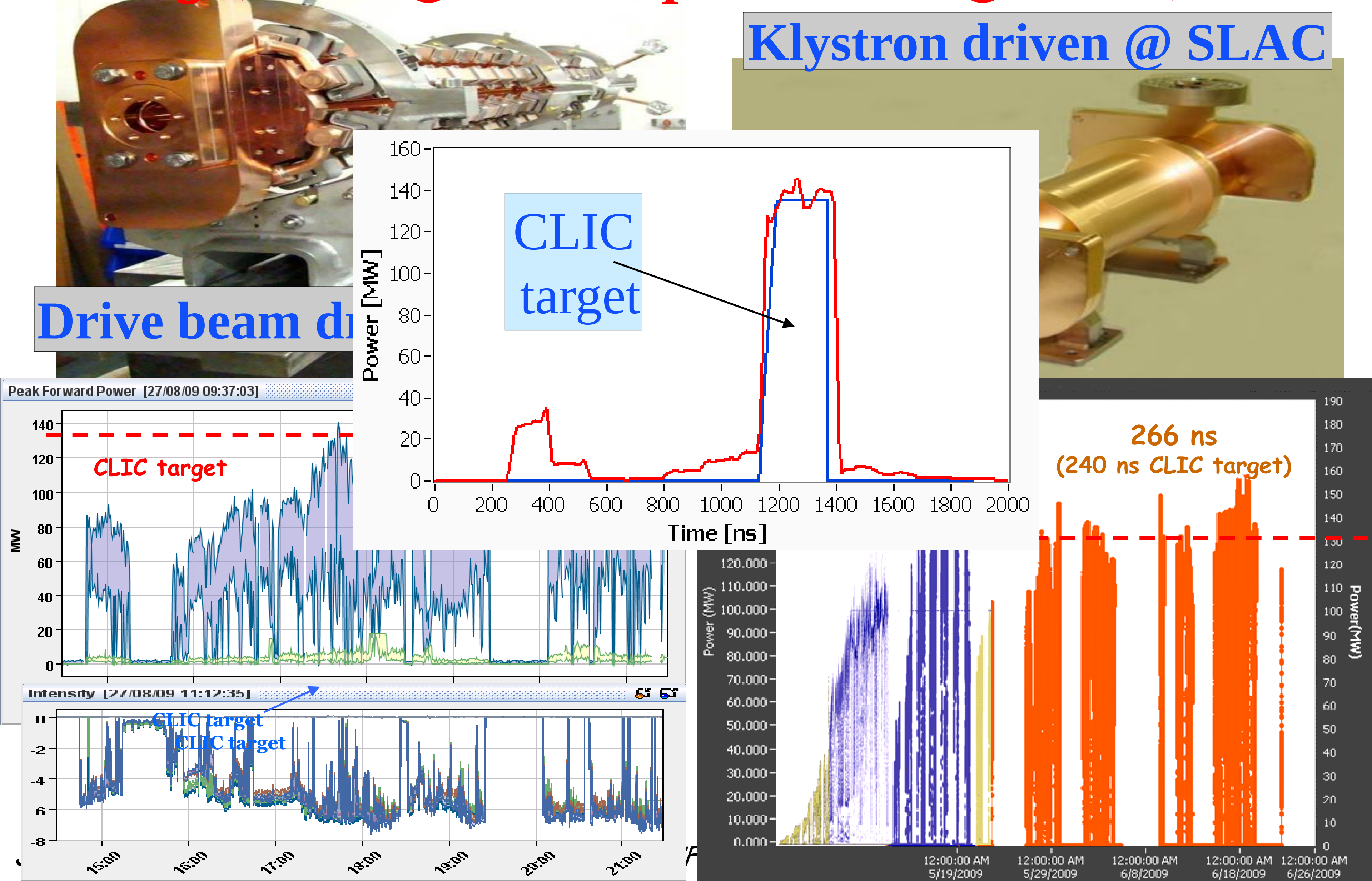
Parameter	Symbol	LCLS	CXFEL	Unit
Bunch Charge	Q	250	250	pC
Electron Energy	E	14	6	GeV
Emittance	$\gamma\varepsilon_{x,y}$	0.4-0.6	0.4-0.5	μm
Peak Current	I_{pk}	3.0	3.0	kA
Energy Spread	σ_E/E	0.01	0.02	%
Undulator Period	λ_u	3	1.5	cm
Und. Parameter	K	3.5	1.9	
Mean Und. Beta	$\langle\beta\rangle$	30	8	m
Sat. Length	L_{sat}	60	30	m
Sat. Power	P_{sat}	30	10	GW
FWHM Pulse Length	ΔT	80	80	fs
Photons/Pulse	N_γ	2	0.7	10^{12}

PSI-XFEL X-BAND STRUCTURE

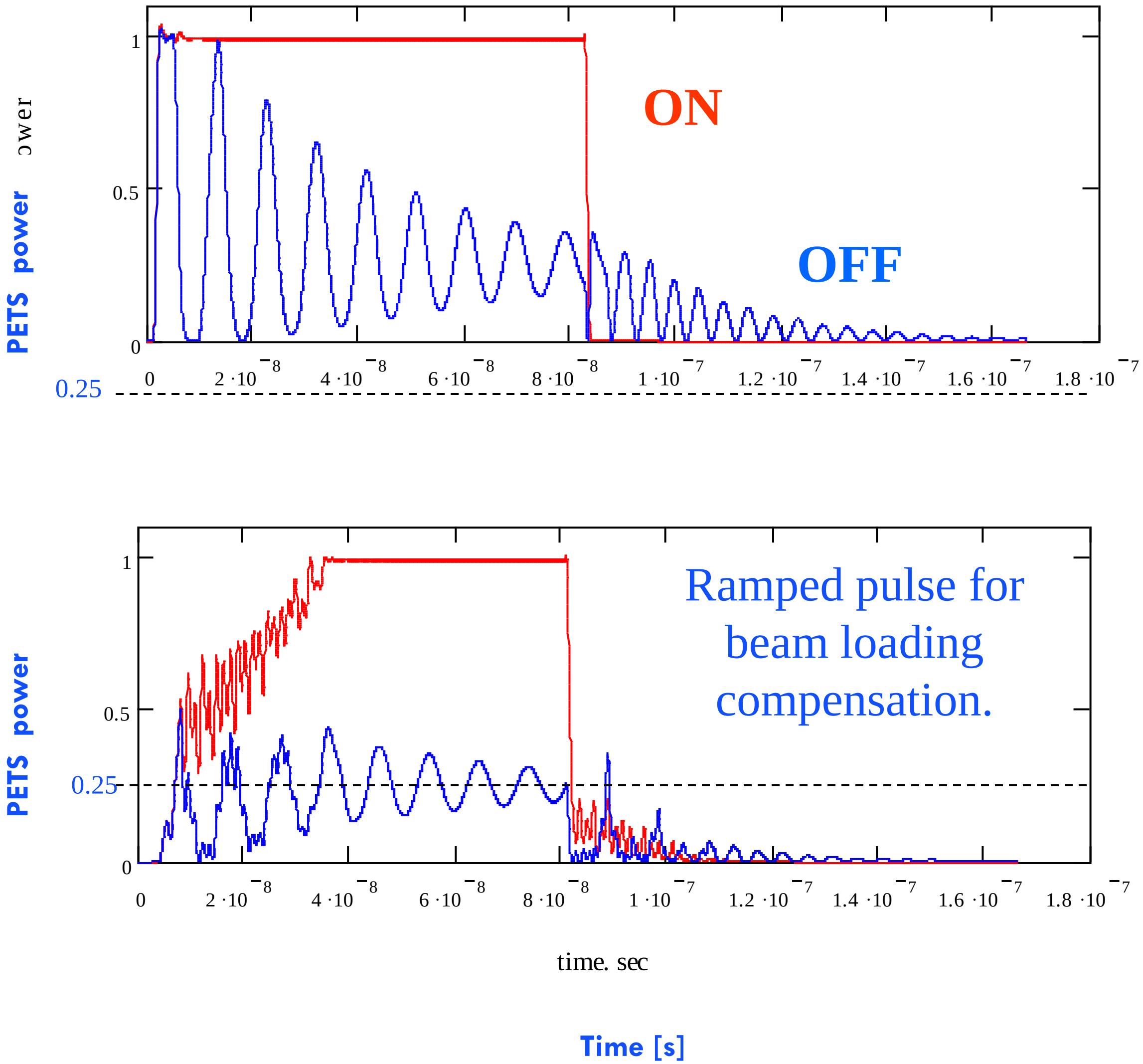


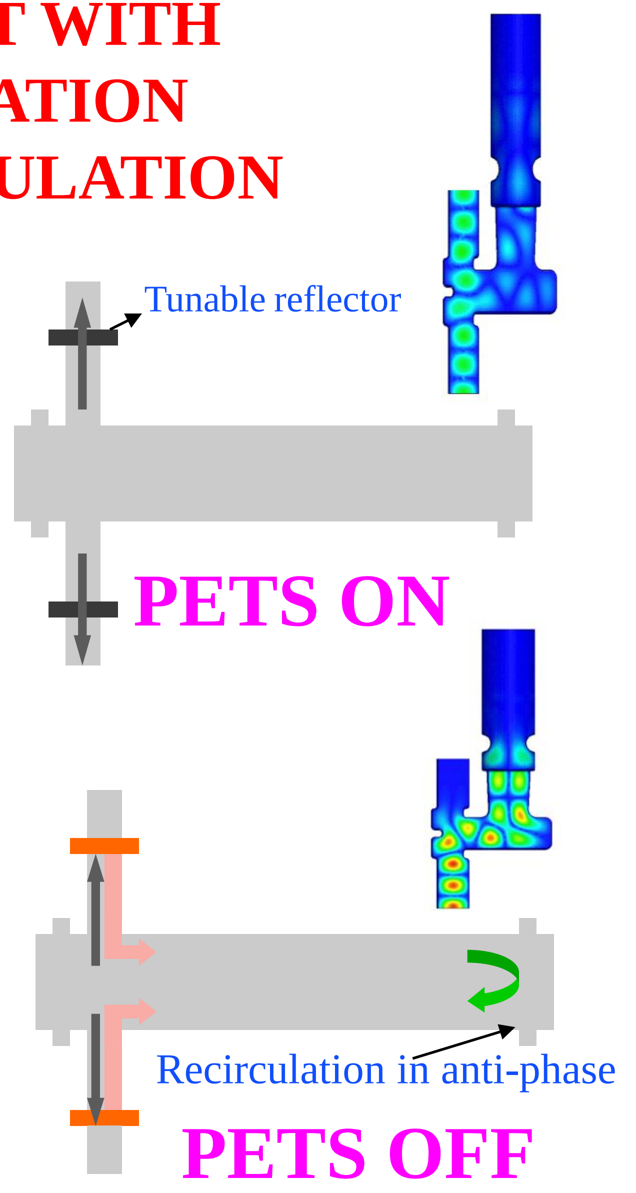
11.994 GHZ, 73 cells, non-damped, sealed, disks Ø65mm, push-pull tuning

Power Production Structure (PETS) design, built @ CERN, power tests @ CTF3, SLAC

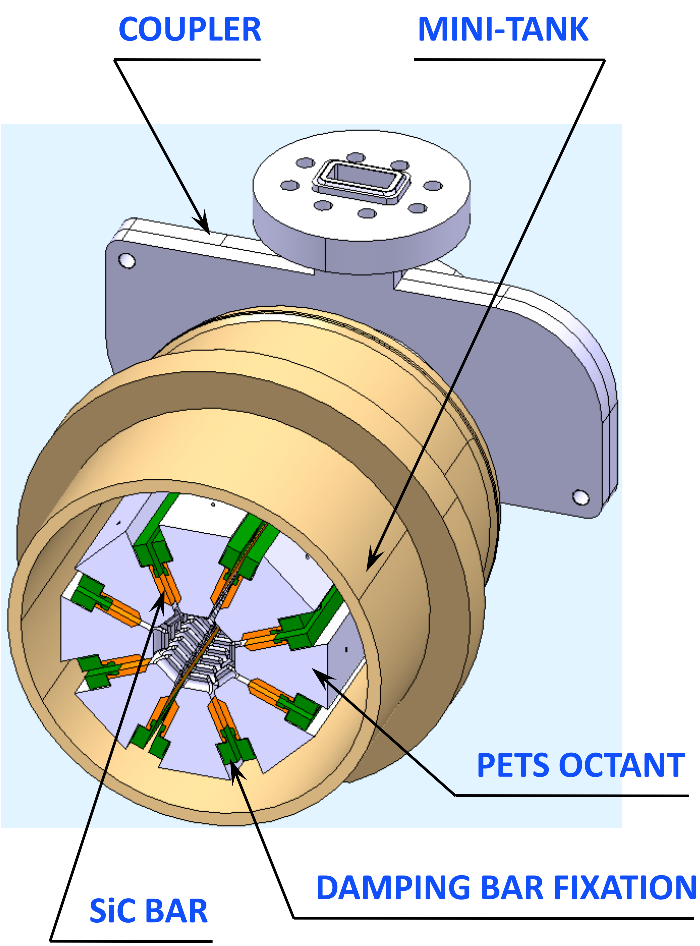


PETS ON/OFF CONCEPT WITH EXTERNAL COMMUTATION AND INTERNAL RECIRCULATION



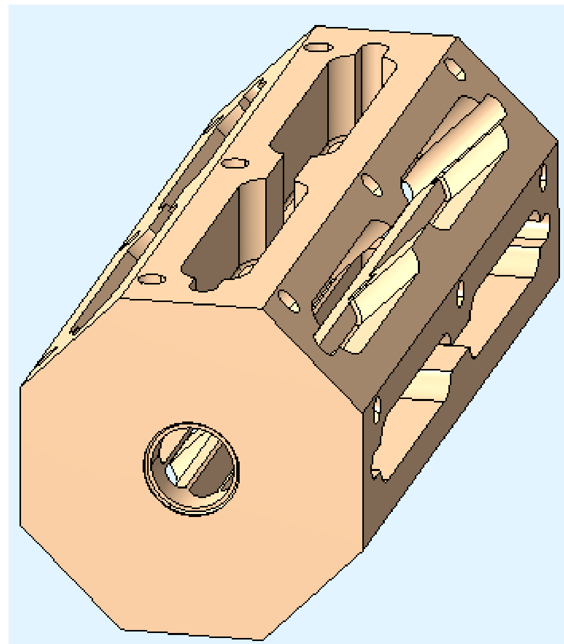


PETS



PETS with damping material

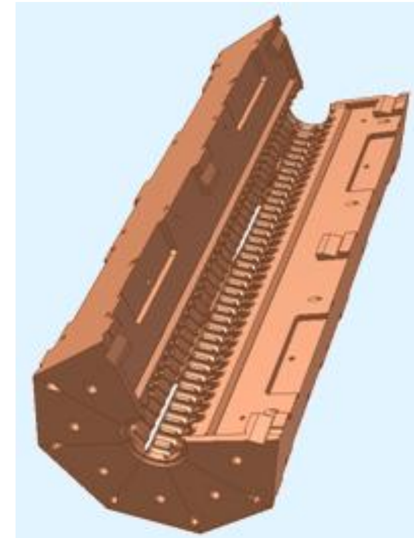
PETS mockup for test module in the lab



CU-OFE octal prism with slots

The internal surface area calculation was done with CATIA Engineering optimizer module.

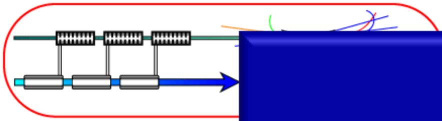
S_2=209235.153 mm^2



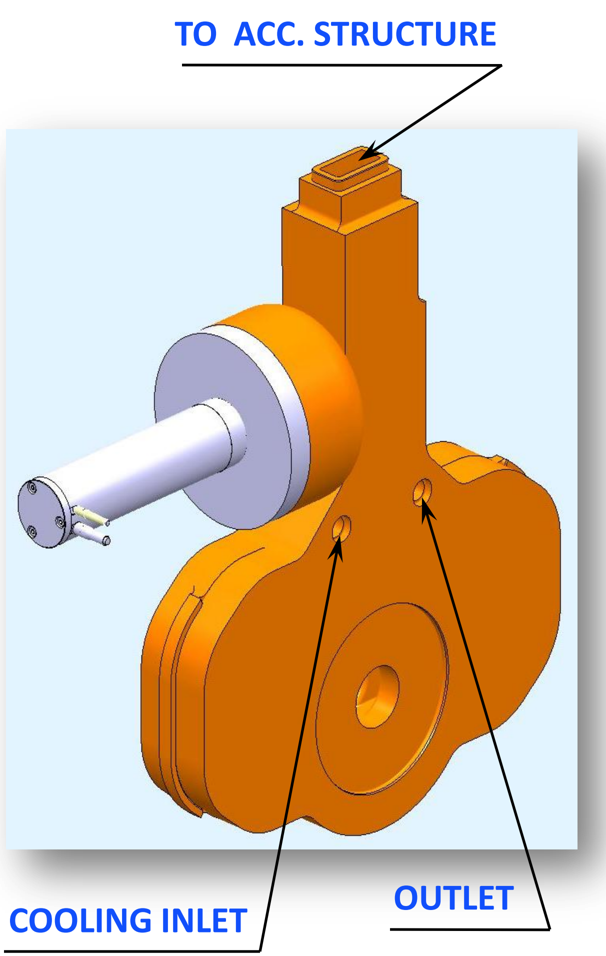
PETS octants assembly

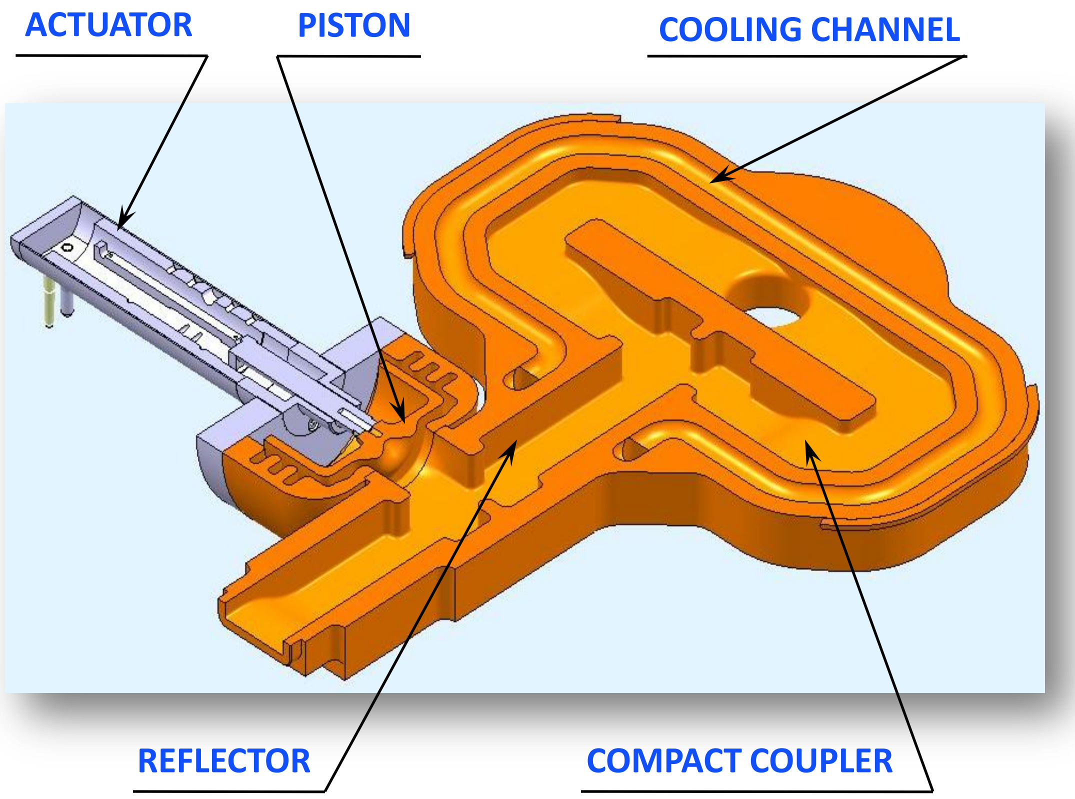
S_1=212838.222 mm^2

26



PETS ON-OFF MECHANISM

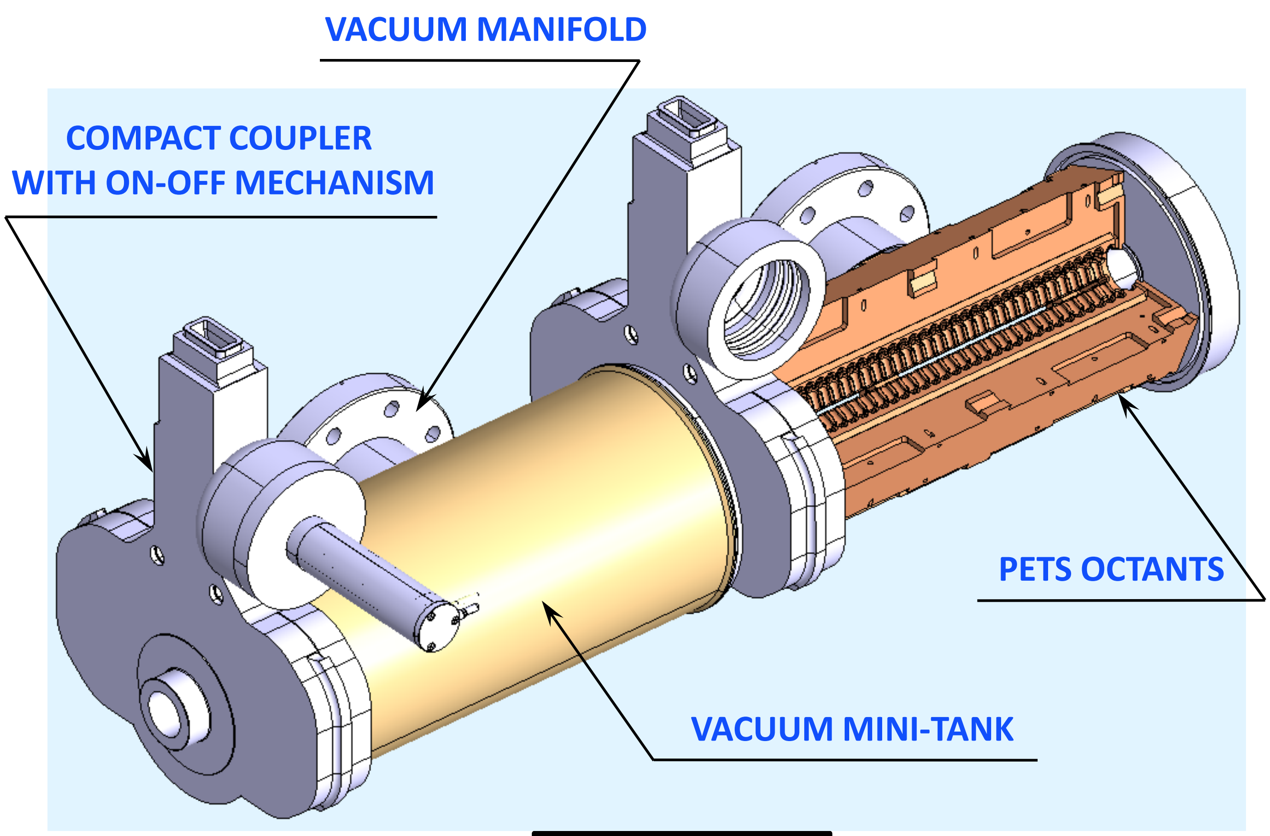




Assembly of PETS "On-Off" mechanism combined with compact coupler

PETS

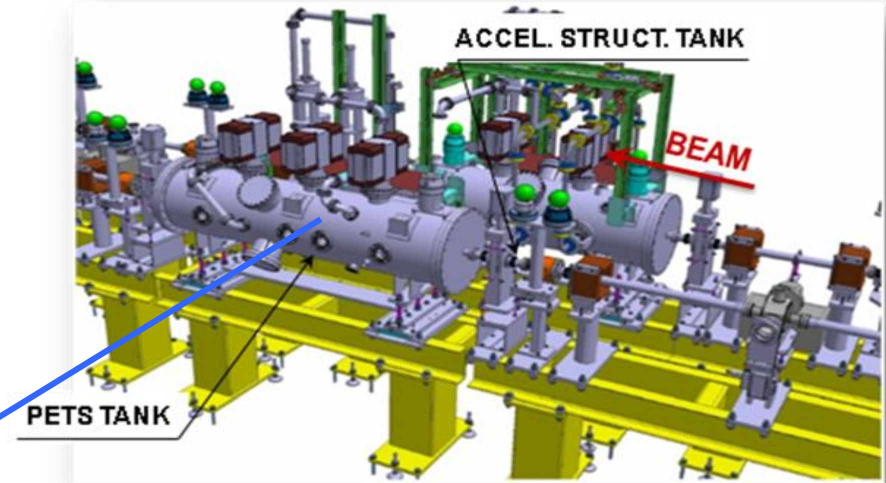
Structure (8 octants) with "compact" couplers, Vacuum "Mini-tank", "On-off" mechanism (*t «off» → 20 ms*)
Cooling circuits (size for 0.5% beam loss, couplers water-cooled, bars cooled by conduction)

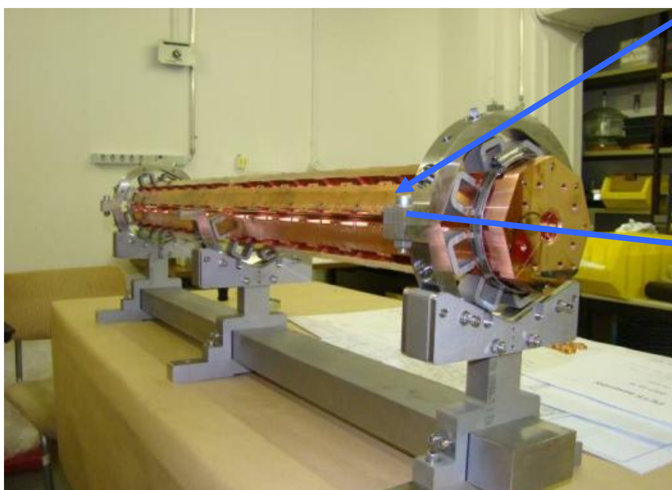


PETS for CLIC

PETS prototype is currently under production by CIEMAT. (EUCARD WP9.2)

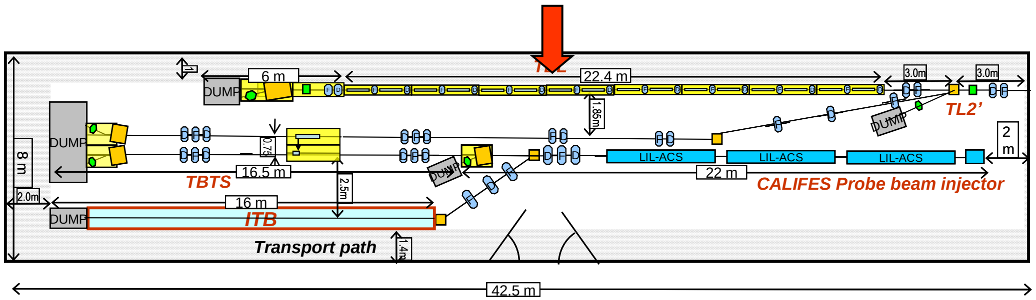
Two Beam Test Stand (TBTS) in CTF3/CLEX





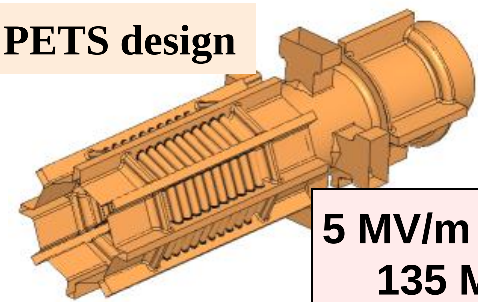
All hardware installed!
Beam in both lines up to end !
Commissioning with beam: PETS 2009, Two Beam Acceleration 2010

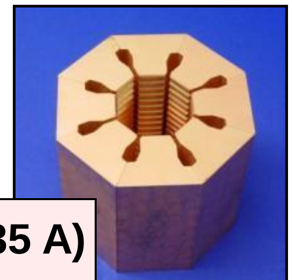
Test Beam Line (TBL)



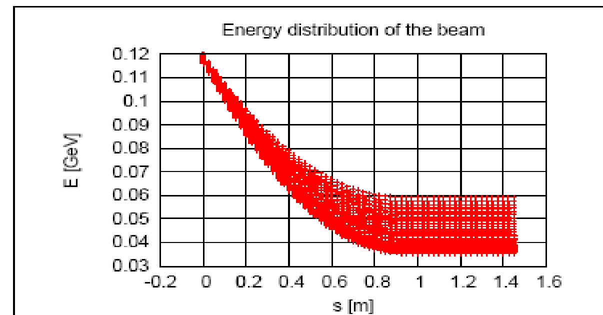
- **High energy-spread beam transport decelerate to 60 % beam energy**
- **Drive Beam stability**
- **Stability of RF power extraction total power in 16 PETS: 1.5 GW**
- **Alignment procedures**

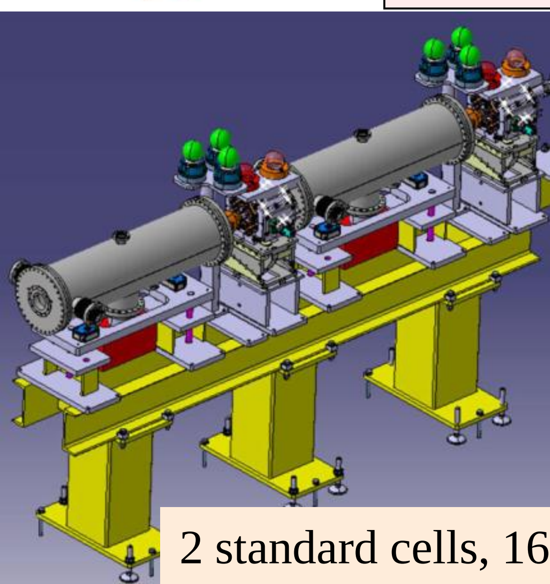
PETS design



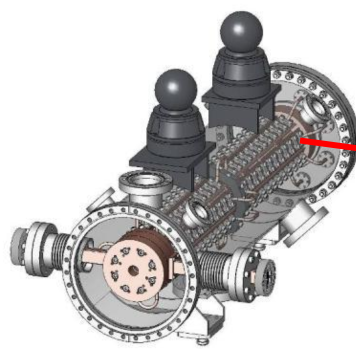


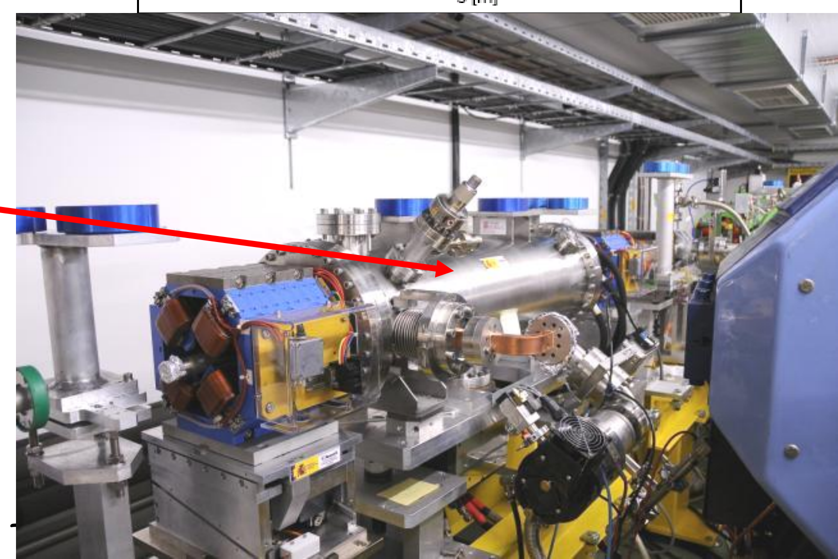
5 MV/m deceleration (35 A)
135 MV output Power



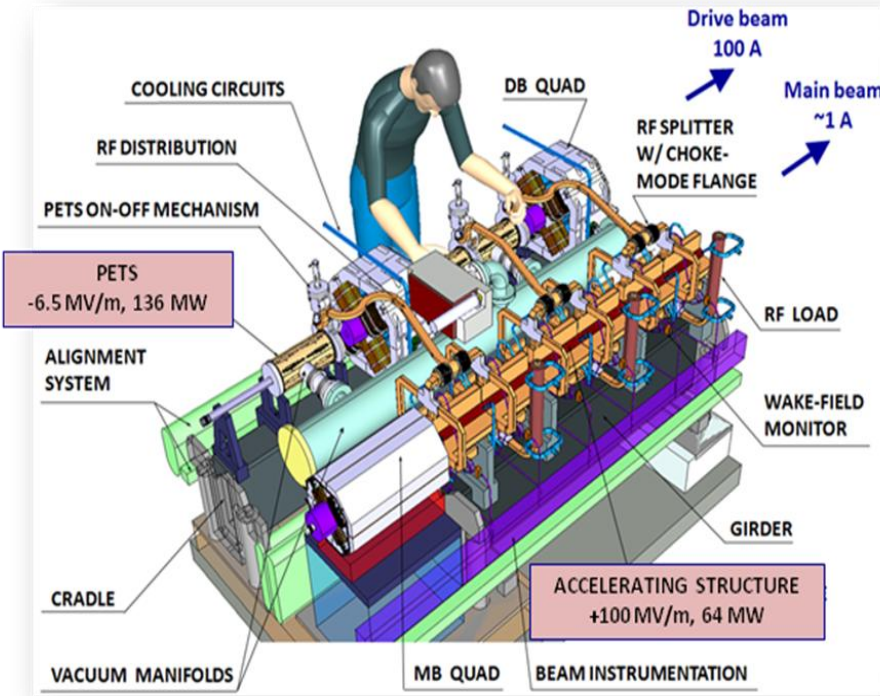


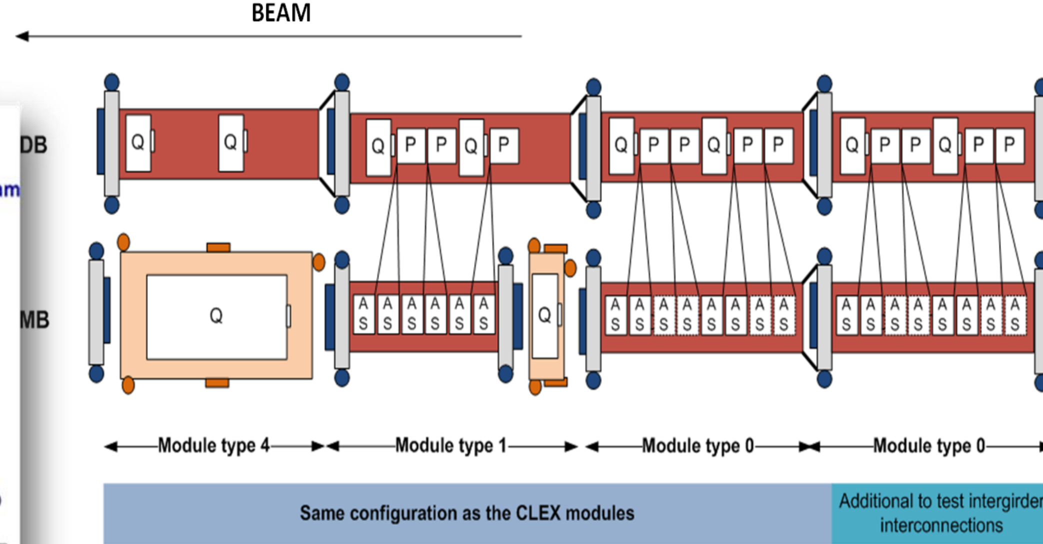
2 standard cells, 16 total



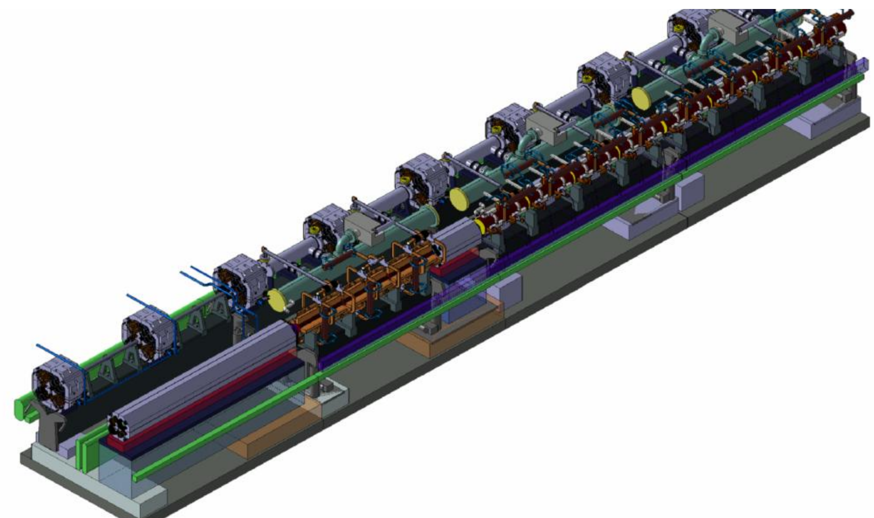


Two Beam Module tests in CTF3/CLEX





NUMBER OF CLIC MODULES 20924	ACCELERATING STRUCTURES - 142812 PETS - 71406	QUADRUPOLES: Main Beam – 3992 Drive Beam – 41848

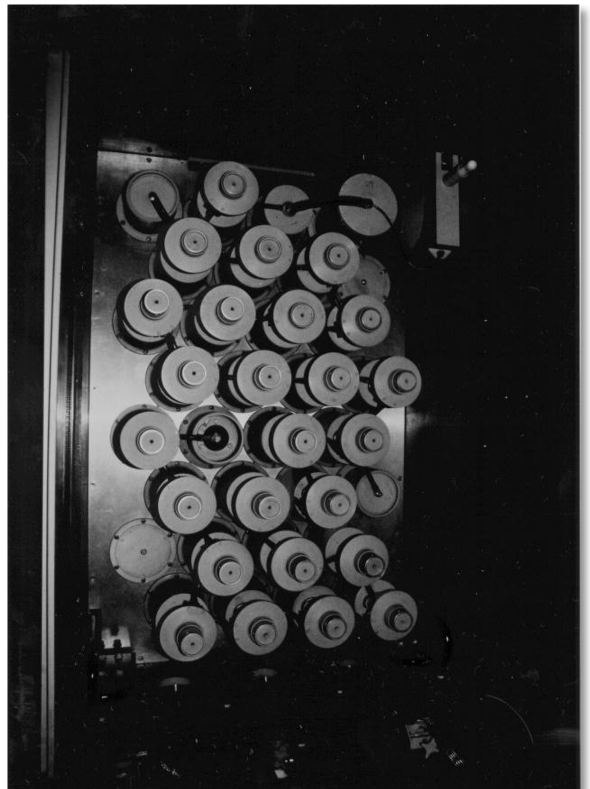


Test module representing all module types & integrating all various components:
RF structures, quadrupoles, instrumentation, alignment, stabilization, vacuum, etc
Tests without beam in 2010-11, with beam in CTF3/CLEX in 2012-13

Fire in CTF3 Klystron Gallery (04/03/10)

Cleaning overall gallery ➡ six months delay…..

Modulator in Gallery

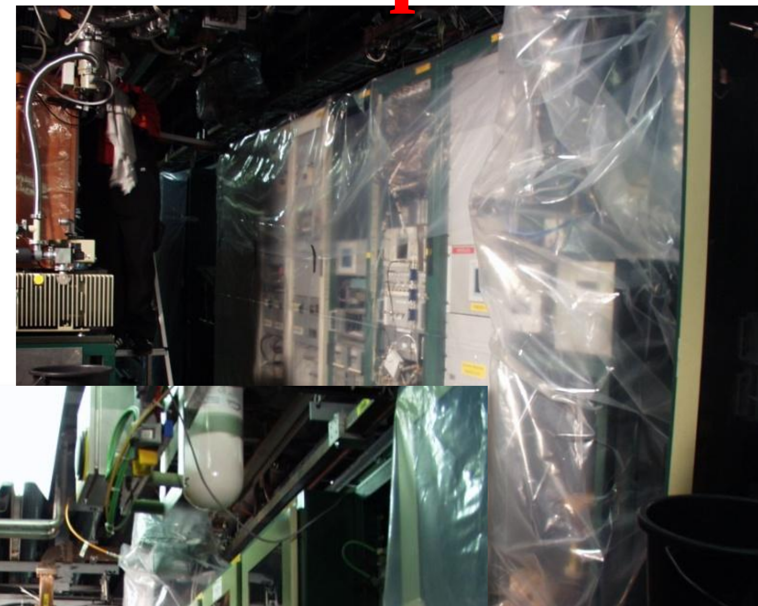


Pulse Forming Network
in Faraday Cage

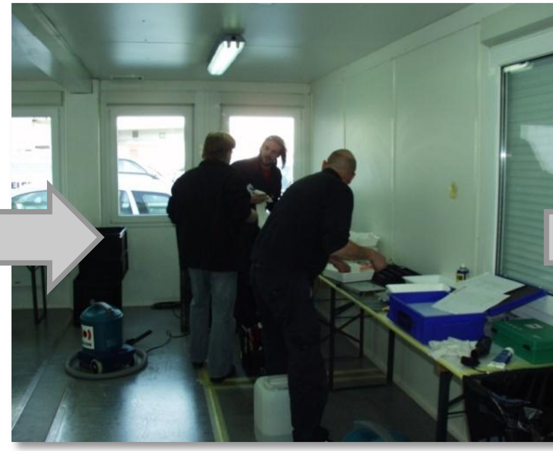
Pulse Forming Network
after fire

Faraday Cage MDK13 ➡ 13 = bad luck?

CTF3 Klystron gallery during cleaning of corrosive products



Cleaning procedure



Components from each rack dismounted and identified

Dust removal from sub components

Chemical cleaning

Cleaned components waiting for reinstallation in gallery

Vacuum ovens for 2nd stage

Ovens for drying after chemical cleaning

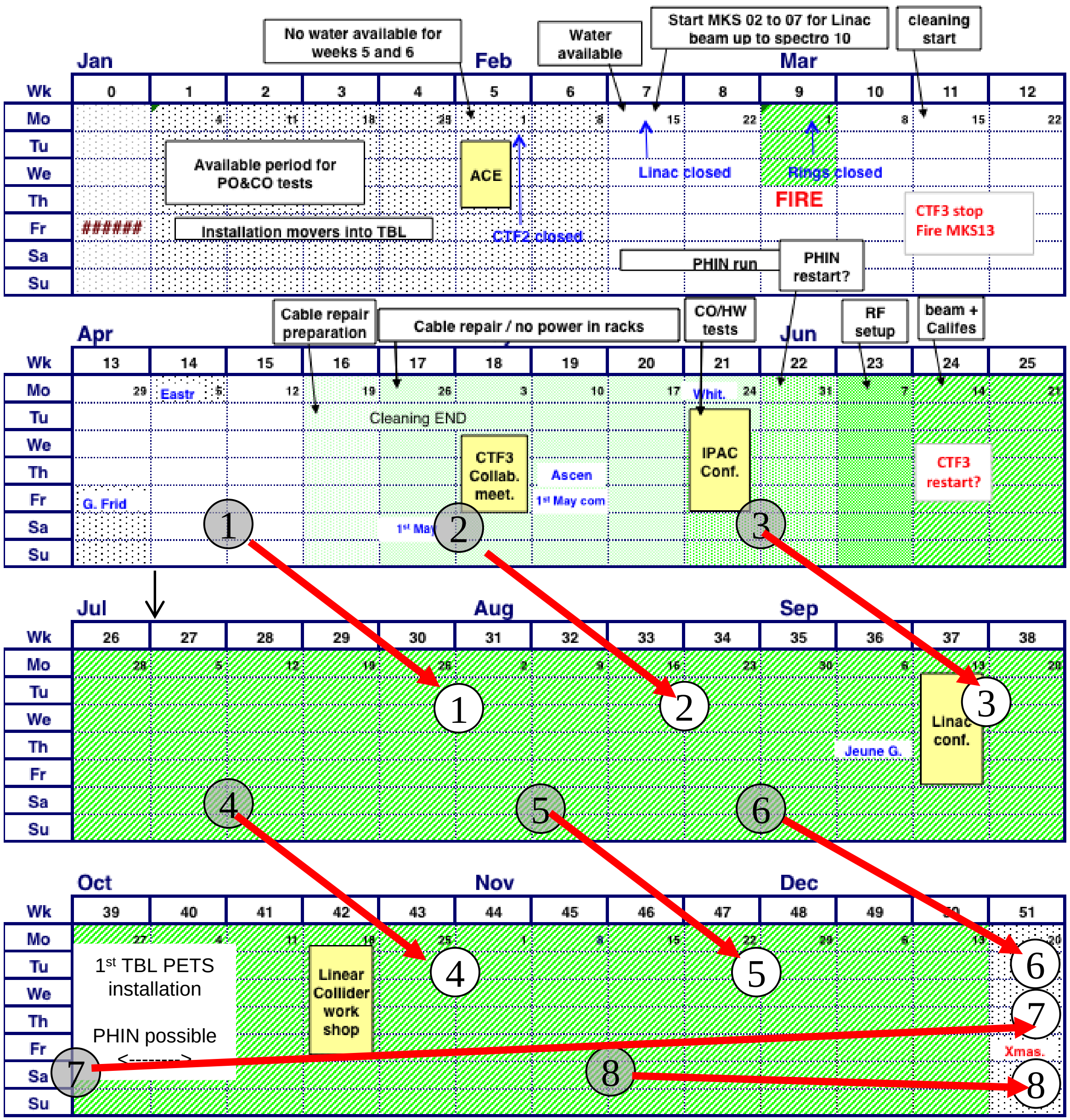
Damaged cables

- >300 cables and ~40 HV vacuum cables in front of PFN damaged
- All cables will be repaired – 4 ½ weeks estimated => until 26 May
  - complete replacement (vacuum)
  - replace damaged section with connectors at both ends

- consequence:
  - all power still disconnected in the klystron gallery => until 20 May
  - vacuum pumps off in Delay Loop, Combiner Ring + part of linac

- Main worry: testing of connections (plus cleaned electronic racks…) => bumpy start-up?

Updated CTF3 Schedule (six months delay)



1 Optics improvements (DL dispersion)
Full transport to CLEX
Bunch length control (first tests)
TBTS initial PETS tests
CALIFES setup
new setup when MKS13 available?

2 PETS conditioned to nominal power/pulse length
TBL PETS tests

3 Accelerating structure conditioned to nominal power/pulse length — Two-Beam test power & energy gain, 100MV/m

4 TBL studies (limited) — PETS breakdown rate measurements???

5 Measurement of breakdown kicks — Beam Loading compensation experiment

6 Measurement of effect of beam loading on breakdown rate

7 Test of new PETS on-off scheme

8 TBL studies 30% deceleration ?

2nd TBL PETS installation

6 weeks PHIN phase-coding Laser preparation

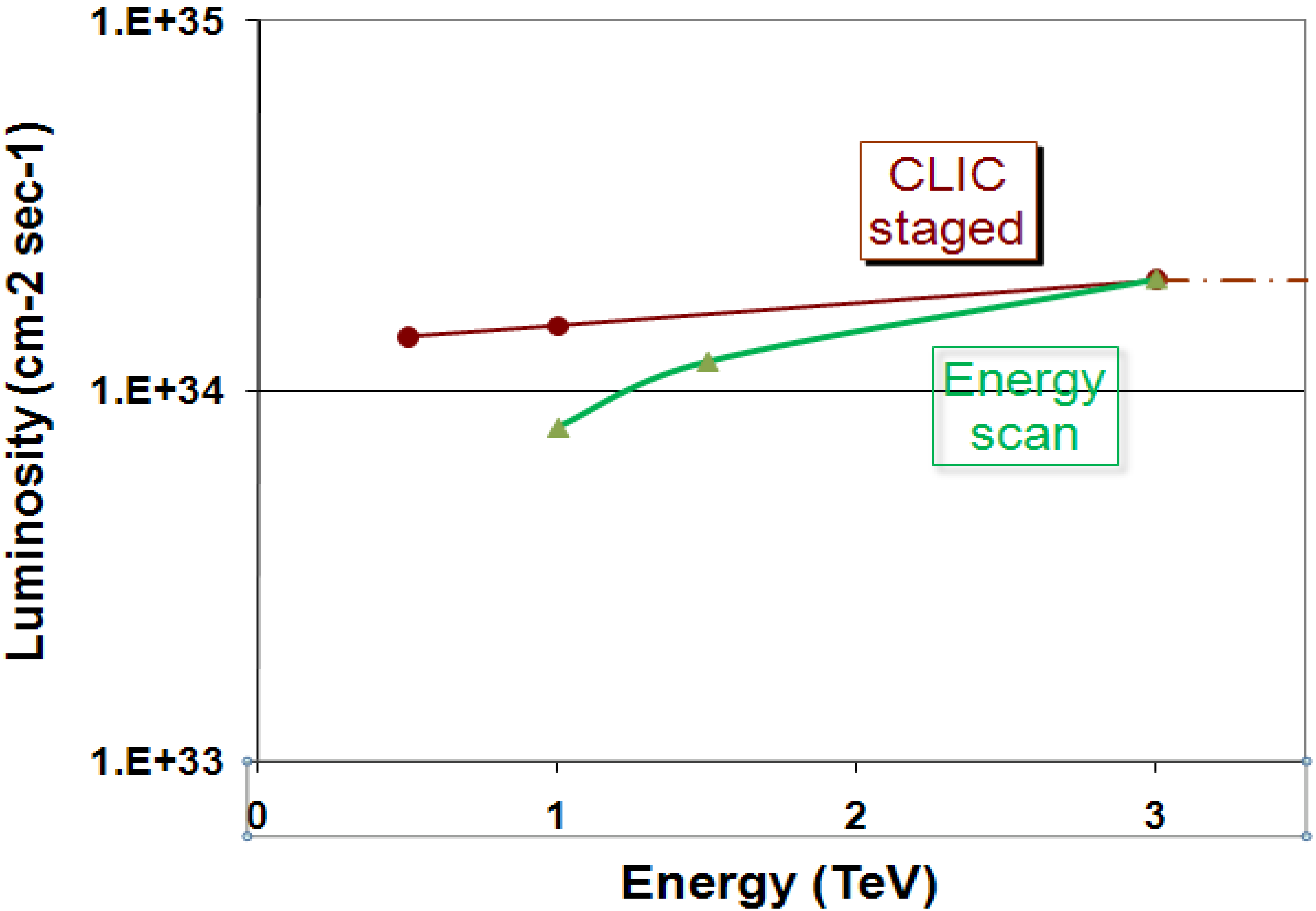
- Stability studies & improvements
- PETS no recirculation
- Phase stability
- Operation at 5 Hz (or more)
- Control of beam losses
- Coherent Diffraction Radiation …

Beam driven RF Power Generation Feasibility

Item	Feasibility Issue	Unit	Nominal	Achieved	How	Feasibility
Beam Driven RF power generation	PETS RF Power	MW	130	130	TBTS/SLAC	✓
	PETS Pulse length	ns	170	>170	TBTS/SLAC	✓
	PETS Breakdown rate	/m	< 1·10-7	1.2·10-6	TBTS/SLAC	2010
	PETS ON/OFF	-	@ 50Hz	-	CTF3/TBTS	2010-11
	Drive beam to RF efficiency	%	90%	-	CTF3/TBL	2010-11
	RF pulse shape control	%	< 0.1%	-	CTF3/TBTS	

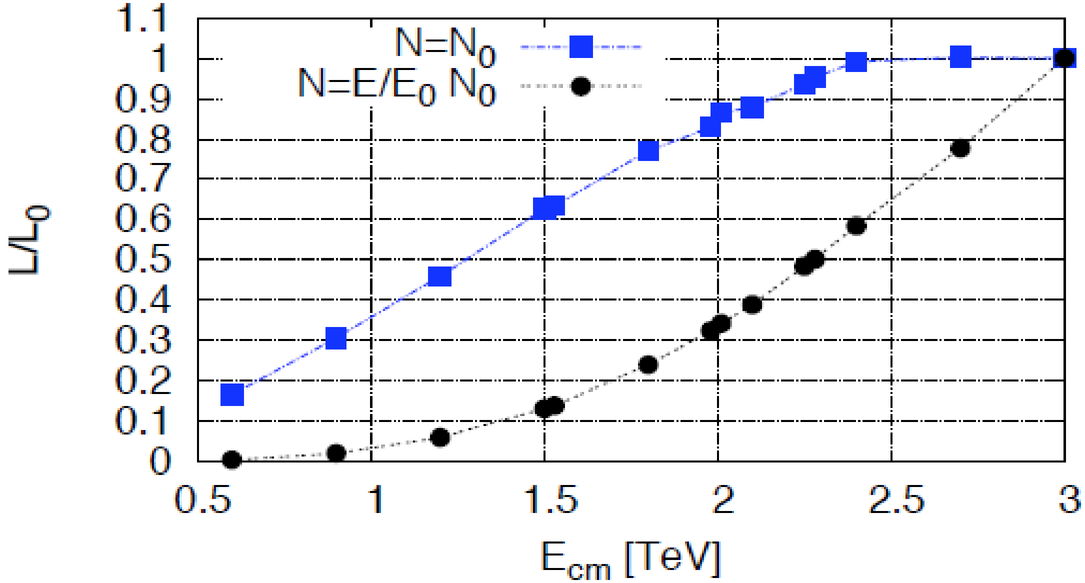
- **RF power generation by single PETS feasibility demonstrated except for breakdown rate.**
- **ON/OFF mechanism being built, still to be tested**
- **Efficient RF power extraction in multiple stages being addressed in TBL under construction for tests with beam**
- **Tests delayed to 2011 by CTF3 modulator fire**

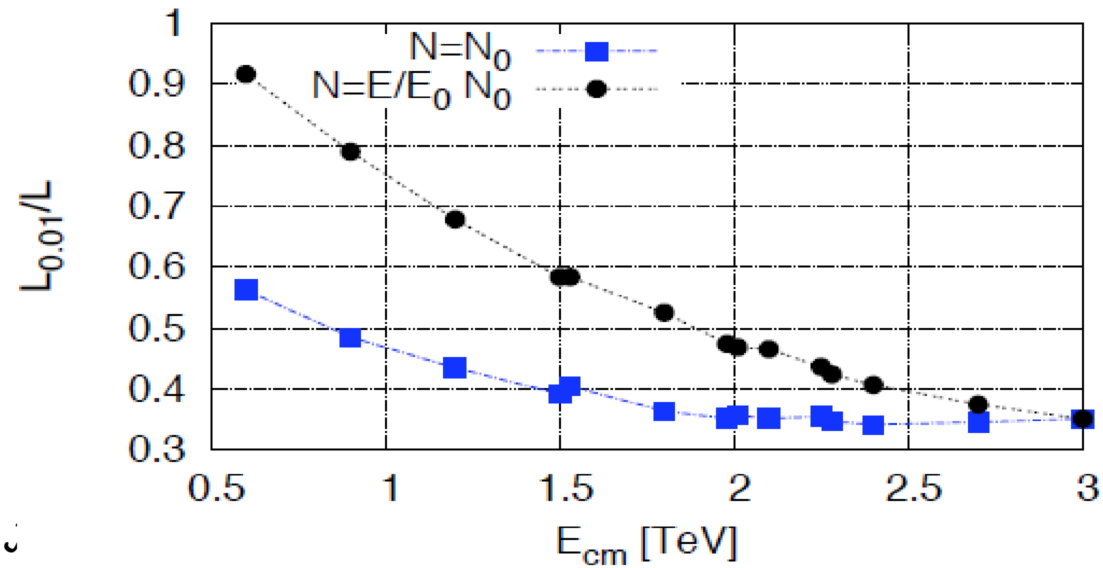
CLIC performances and energy scan



Beam collision energy (E) adjustement by accelerating gradient (G) tuning

Charge per bunch Q proportional to gradient G for beam stability





G= G0*E/E0

→

Q = Q0*G/G0

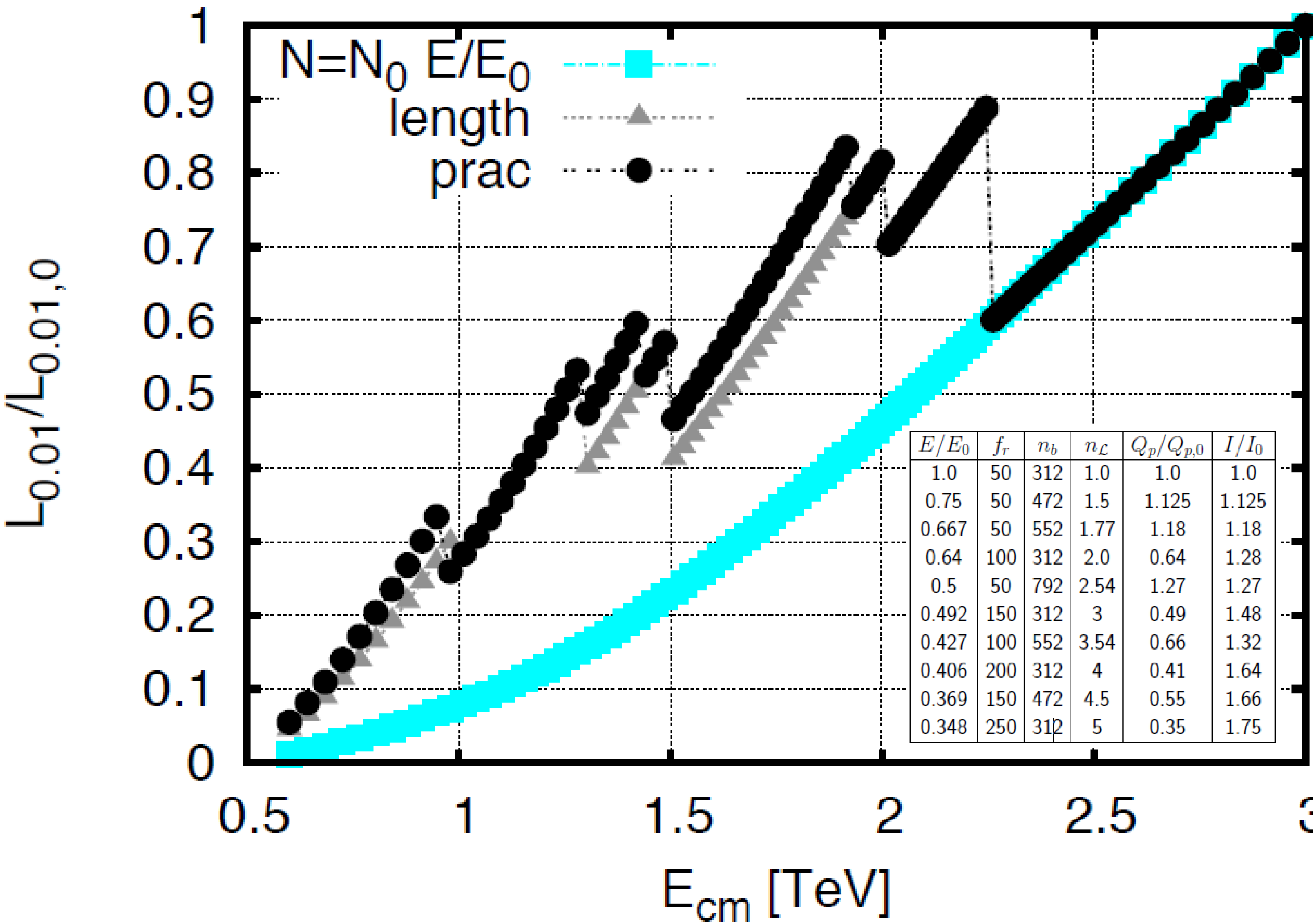
→

Luminosity reduction

→

Better energy spectrum

Luminosity recovery by beam pulse lengthening and repetition frequency



E/E_0	f_r	n_b	$n_{\mathcal{L}}$	$Q_p/Q_{p,0}$	I/I_0
1.0	50	312	1.0	1.0	1.0
0.75	50	472	1.5	1.125	1.125
0.667	50	552	1.77	1.18	1.18
0.64	100	312	2.0	0.64	1.28
0.5	50	792	2.54	1.27	1.27
0.492	150	312	3	0.49	1.48
0.427	100	552	3.54	0.66	1.32
0.406	200	312	4	0.41	1.64
0.369	150	472	4.5	0.55	1.66
0.348	250	312	5	0.35	1.75

Conceptual Design Report

Contribution/Authors by CLIC collaborators

https://edms.cern.ch/nav/CERN-0000060014/AB-003131

3 volumes: similar to ILC CDR:

- **Vol1: Executive Summary**
- **Vol2: The CLIC accelerator and site facilities**
- **Vol3: The CLIC physics and detectors**

including detailed value Estimate (specific contribution in vol. 2&3, summary in vol. 1)

Editorial Board for Volume 2:

H.Schmickler (chair), N.Phinney/SLAC, N.Toge/KEK,

Outline defined and contributors contacted

http://indico.cern.ch/getFile.py/access?contribId=3&resId=0&materialId=0&confId=91998

Vol 3 under responsibility of LCD project (L.Linssen)

CDR schedule

Volume 1: Executive Summary

deadline for contributions:	late 2010
preliminary draft (without cost) ready	end 2010
draft volume 1 (without cost) ready	early 2011
volume 1 (with cost) ready	end April 2011

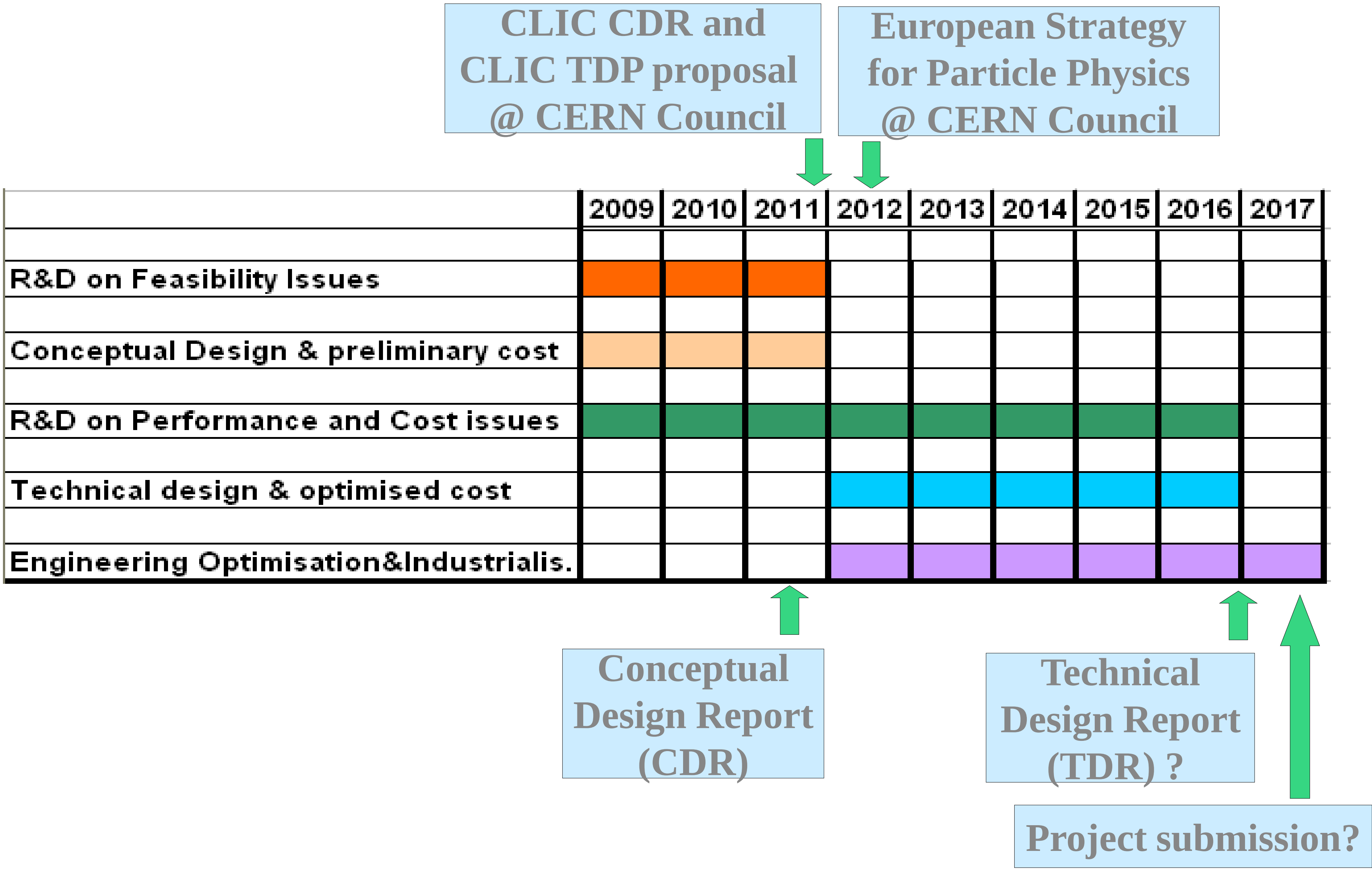
Volume 2: Accelerator

information to the authors	late May 2010
deadline for contributions	end September 2010
draft (without detailed cost) ready	early December 2010
volume 2 (with detailed cost) ready	end April 2011 (depending on CTF3 results)

Volume 3: Detector

volume 3 ready	end April 2011

CLIC Updated Schedule



Extremely fruitful CLIC /ILC Collaboration

- **ILC for a TeV LC based on SC RF technology & CLIC extending LC into Multi-TeV range complementary.**
- **Common working groups on technical subjects with strong synergy between CLIC & ILC**
  - **making the best use of the available resources**
- **developing common knowledge of both designs and technologies on status, advantages, issues and prospects**
- **preparing together by the Linear Collider Community made up of CLIC & ILC experts:**
  - **proposal(s) best adapted to the future HEP requirements**

Joint CLIC & ILC workshop (October 18-22 @ CERN)
(IWLC10: Linear Collider Accelerator and Detectors)

Conclusion

- **Novel CLIC technology to extend Linear Colliders into the Multi-TeV beam colliding energy range with promising performances and challenging parameters**
- **R&D on feasibility issues and concept of 3 TeV multi-TeV Linear collider in a Conceptual Design Report (CDR) by mid 2011**
  - Ambitious Test Facilities: CTF3, ATF1,2, CESR-TA…
  - Exploration to determine LC capabilities & limitations in multi-TeV range
- **Technical design phase (five to six years):**
  - engineering design optimization, technological risks & cost mitigation
- **Linear collider energy, luminosity and appropriate technology to be defined as the best trade-off following:**
  - Physics requirements when better known from LHC/Tevatron results
  - Design performances, technology risk, power consumption and cost

Warm thanks to outstanding contributions of CLIC collaboration in the past, present and …. future

Close CLIC / ILC collaboration extremely beneficial for Linear Colliders in preparation for best possible future HEP facility as requested by Physics and complementary to LHC

Spares

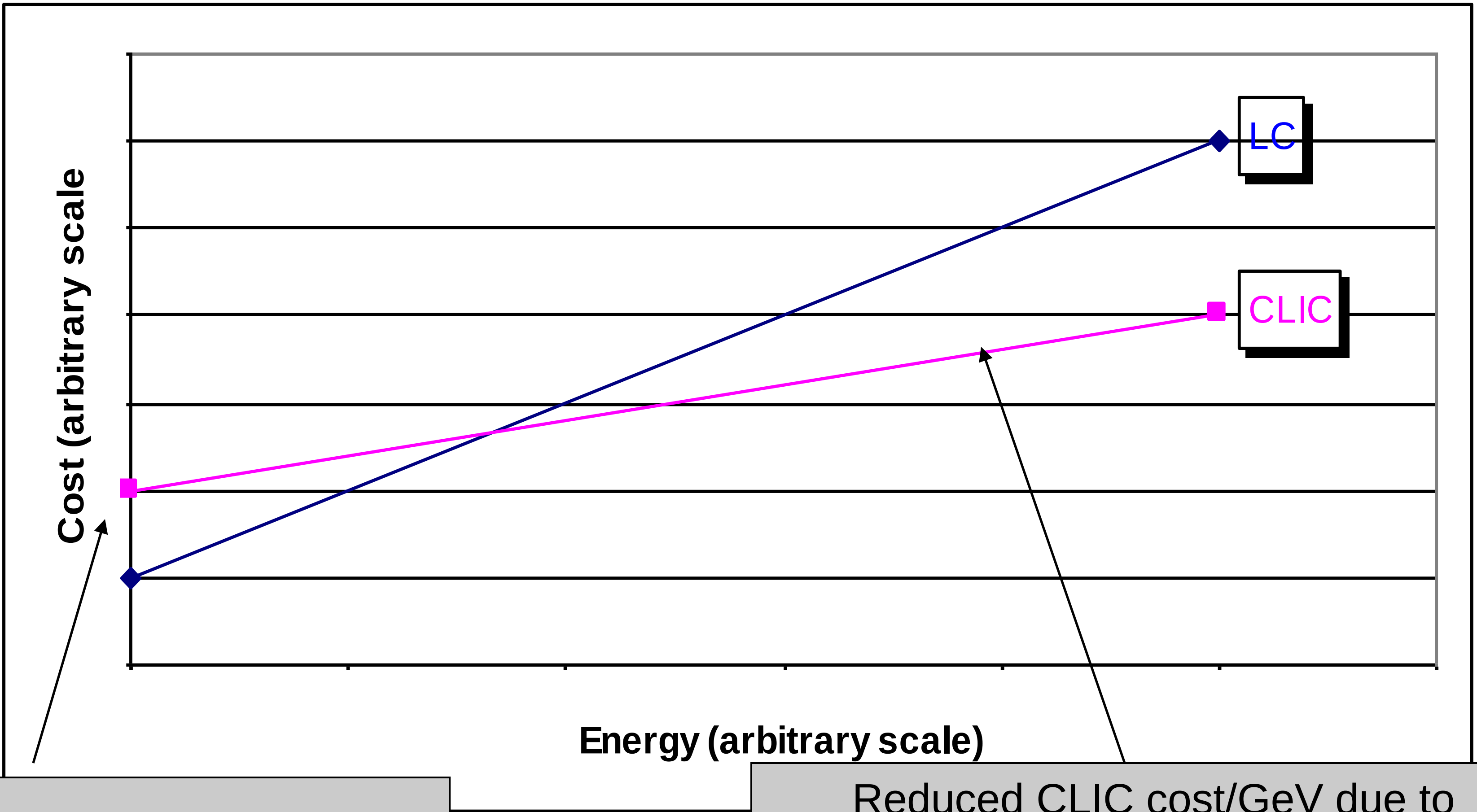
CLIC main parameters

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

Center-of-mass energy	CLIC 500 GeV		CLIC 3 TeV	
Beam parameters	**Relaxed**	**Nominal**	**Relaxed**	**Nominal**
Accelerating structure	502		G	
Total (Peak 1%) luminosity	$8.8(5.8)\cdot10^{33}$	$2.3(1.4)\cdot10^{34}$	$7.3(3.5)\cdot10^{33}$	$5.9(2.0)\cdot10^{34}$
Repetition rate (Hz)	50			
Loaded accel. gradient MV/m	80		100	
Main linac RF frequency GHz	12			
Bunch 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 ($10^{-6}/10^{-9}$)	7.5/40	4.8/25	7.5/40	0.66/20
Hor/Vert FF focusing (mm)	4/0.4	4 / 0.1	4/0.4	4 / 0.1
Hor./vert. IP beam size (nm)	248 / 5.7	202 / 2.3	101/3.3	40 / 1
Hadronic events/crossing at IP	0.07	0.19	0.28	2.7
Coherent pairs at IP	10	100	$2.5\ 10^7$	$3.8\ 10^8$
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.

Relative cost of Linear Colliders

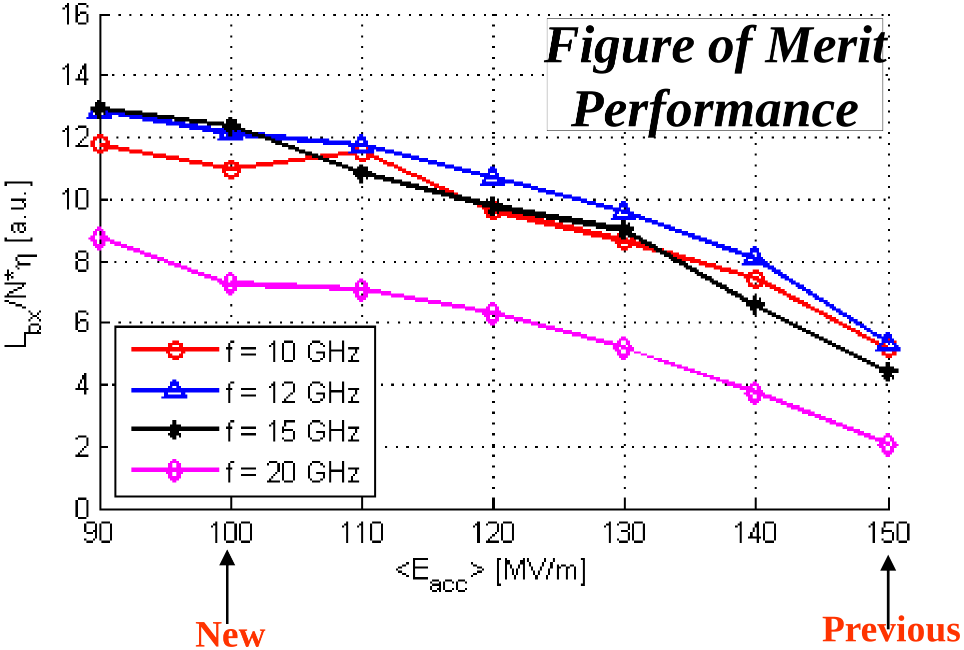


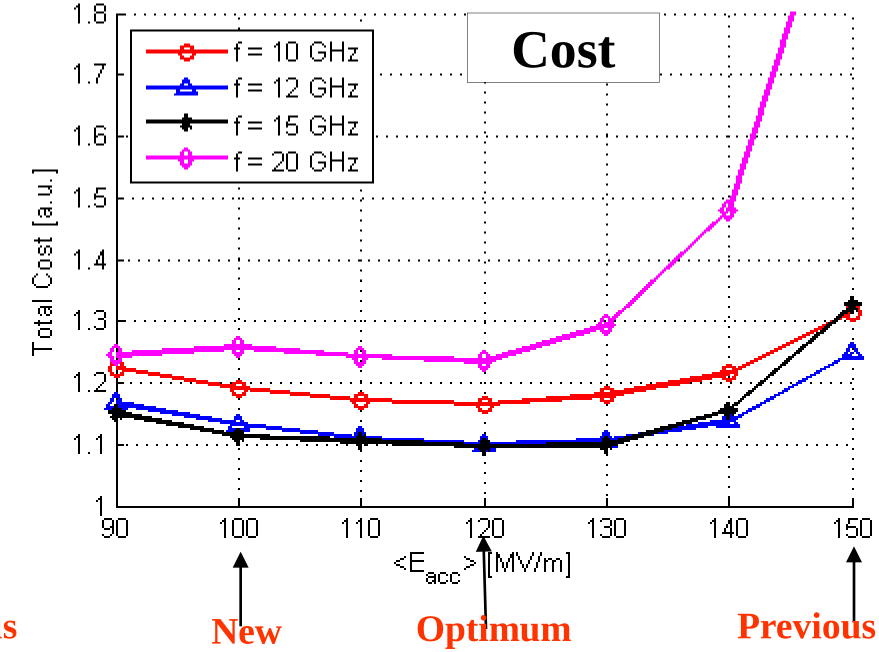
Additional CLIC offset due to drive beam injectors

Reduced CLIC cost/GeV due to
- reduced tunnel length (by 4)
- reduced equipment per meter of tunnel

CLIC performances (FoM) and cost (relative) as a function of the accelerating gradient

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



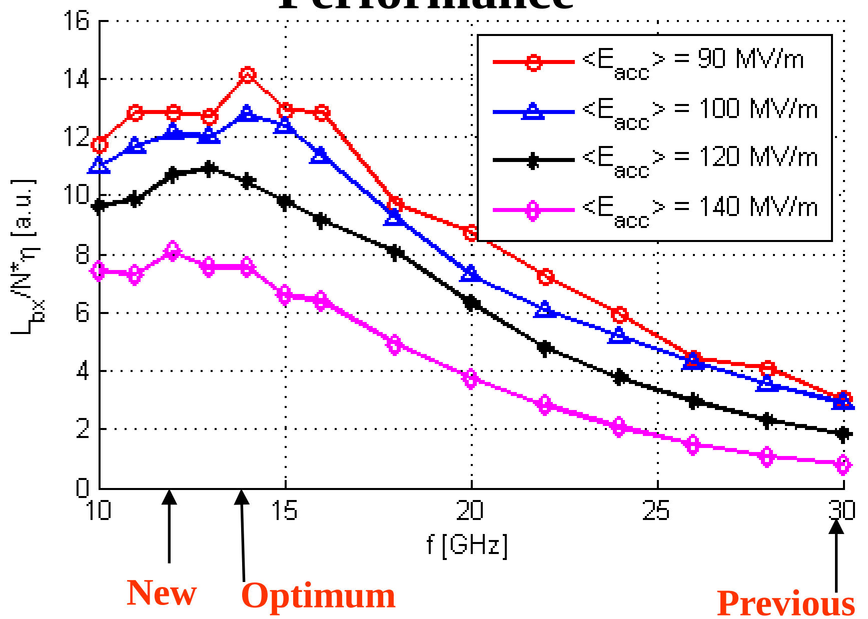


- **Performances increasing with lower accelerating gradient (mainly due to higher efficiency)**
- **Flat cost variation in 100 to 130 MV/m with a minimum around 120 MV/m**

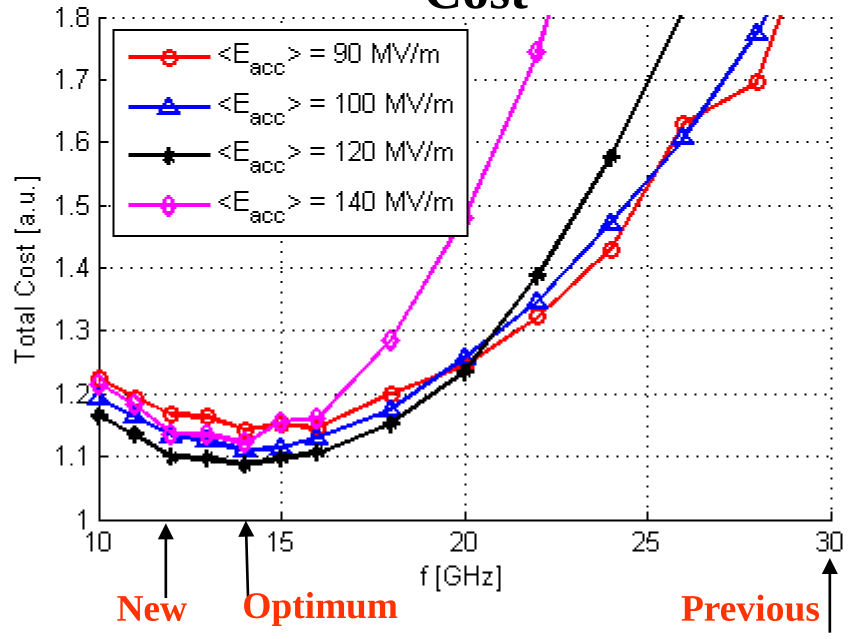
CLIC performances (FoM) and cost optimisation as function of RF frequency

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**

Beam emittance preservation
Beam Dynamics, alignment and stability

Emittance blow-up from Damping Ring to BDS limited:
• in Horizontal to 30% from 500 nrad
• in Vertical to 300% from 5 nrad

Alignment procedure based on:

- **Actif pre-alignment** of beam line components: **15 µm**
- **Beam-based alignment (3 µm)** using BPMs with good resolution (100nm)
- **Alignment of accelerating structures** to the beam using wake-monitors
- **Tuning** based on luminosity/beam size measurement with 2% resolution

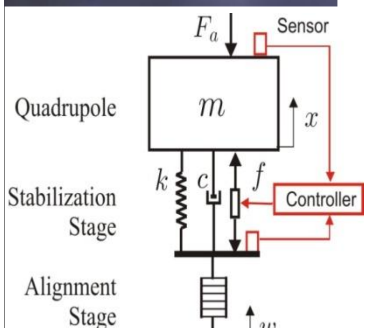
Beam stability by quadrupole stabilisation:0.2nm beam-beam stability@IP

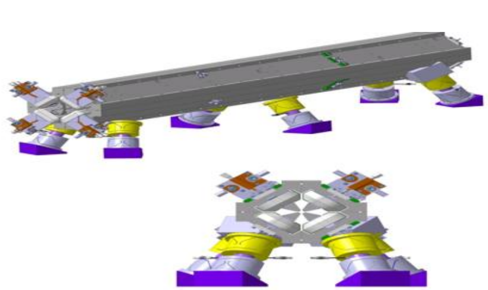
- quadrupole passive and active stabilisation
- beam feedback (pulse to pulse) and Intrabeam feedback

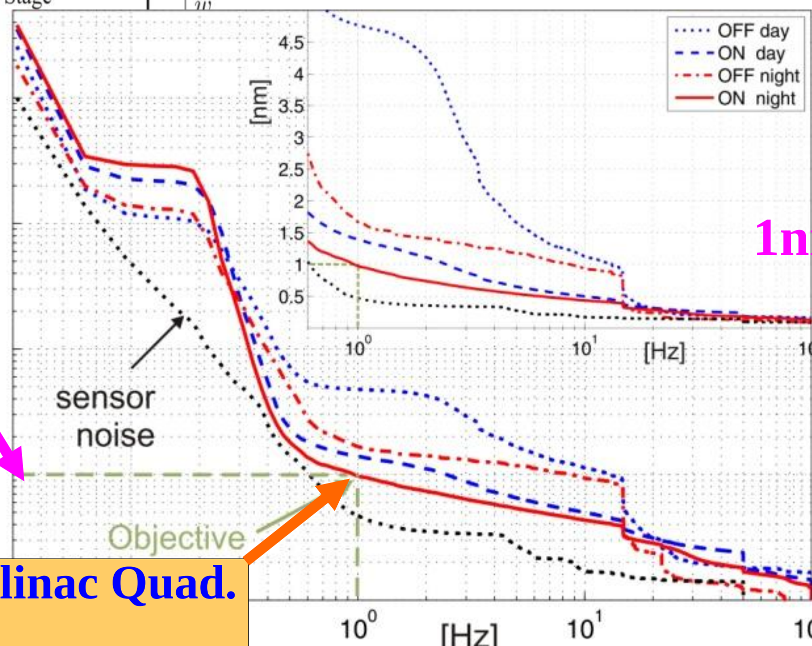
Quadrupole Magnets	Horizontal	Vertical
Linac (2600 quads)	14nm	1.5 nm
Final Focus (2quads)	4 nm	0.5 nm

Test Stands (2 methods) with (future) real quadrupole prototype (400 kg)

Active stabilisation & nano-alignment by Hexapole:

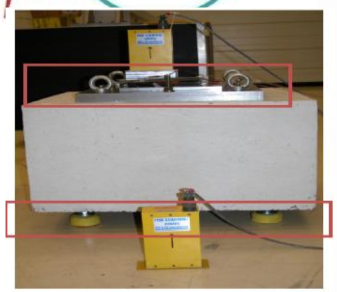


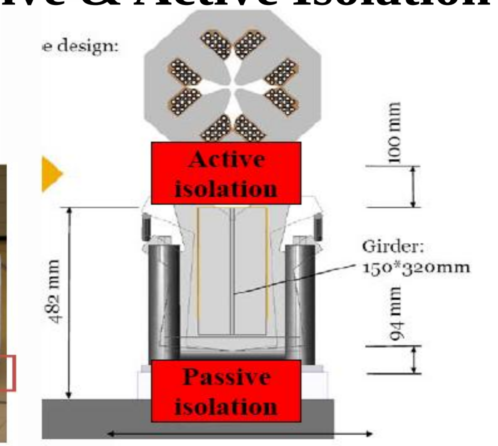


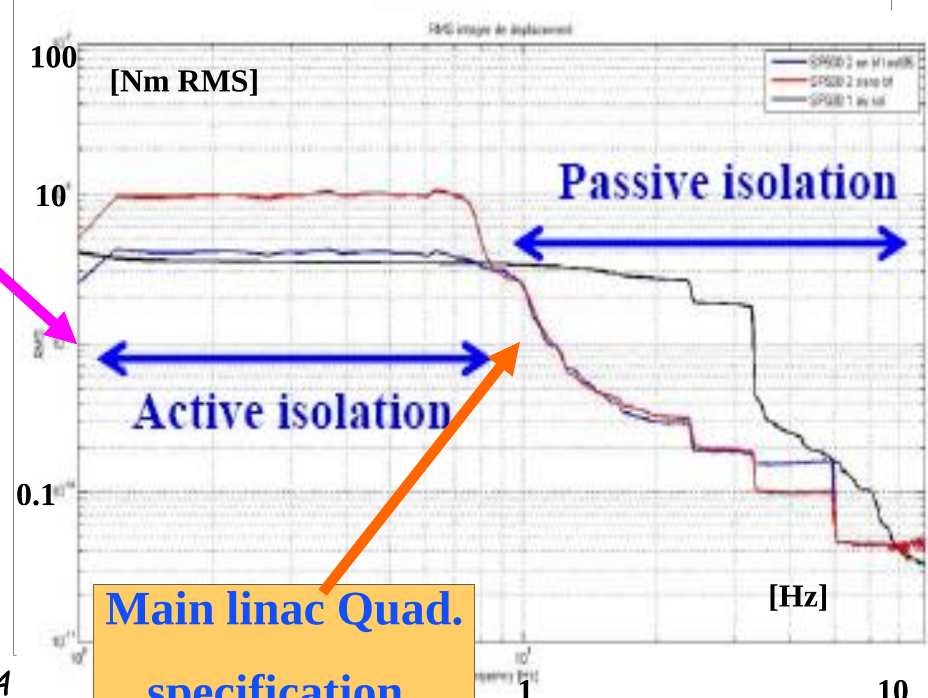


Main linac Quad. specification

Passive & Active Isolation



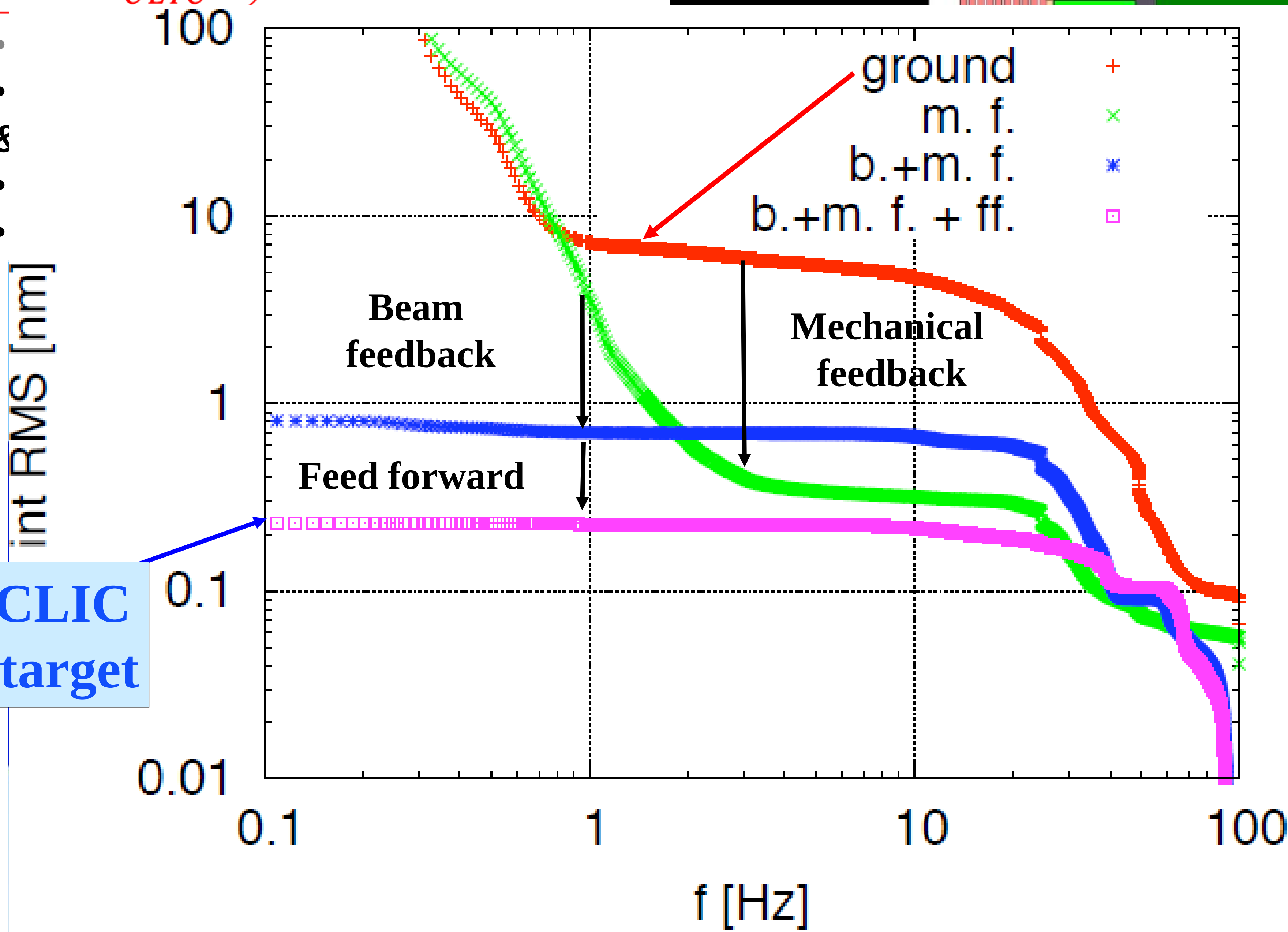




Main linac Quad. specification

Machine Detector Interface

•
•
&
•
•



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Vertex Detector
IP Chamber