The CLIC project

Status and prospect

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On behalf of the CLIC/CTF3 collaboration

SiD Workshop 2013
SLAC, CA, USA, Oct 11, 2013

Overview

CLIC status

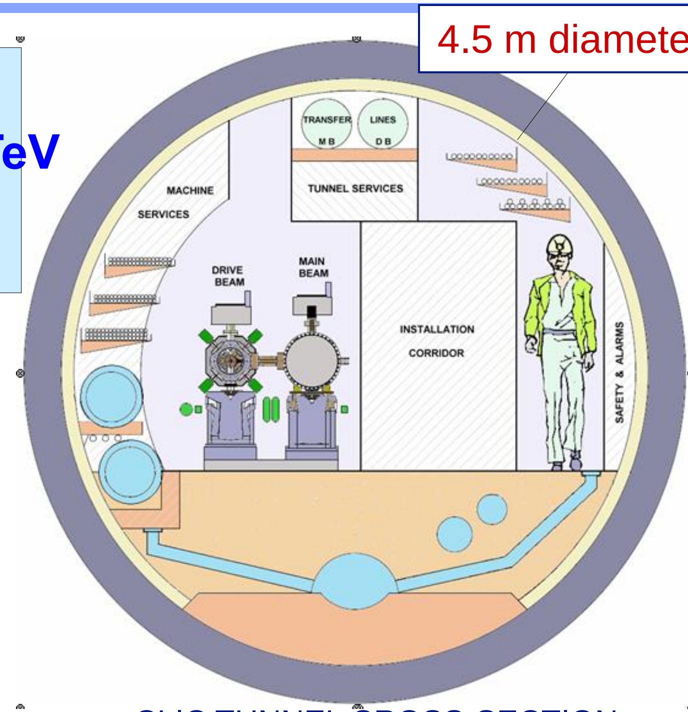
The period 2012-2018

X-band activites

Compact Linear Collider - CLIC

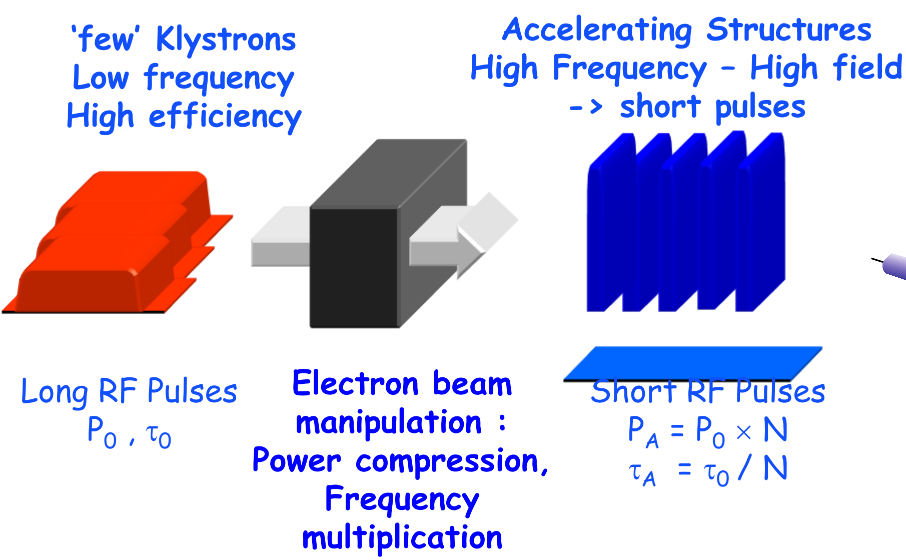
- **High acceleration gradient: > 100 MV/m**
  - **"Compact" collider: total length < 50 km at 3 TeV**
  - **Normal conducting acceleration structures at high RF frequency (12 GHz)**

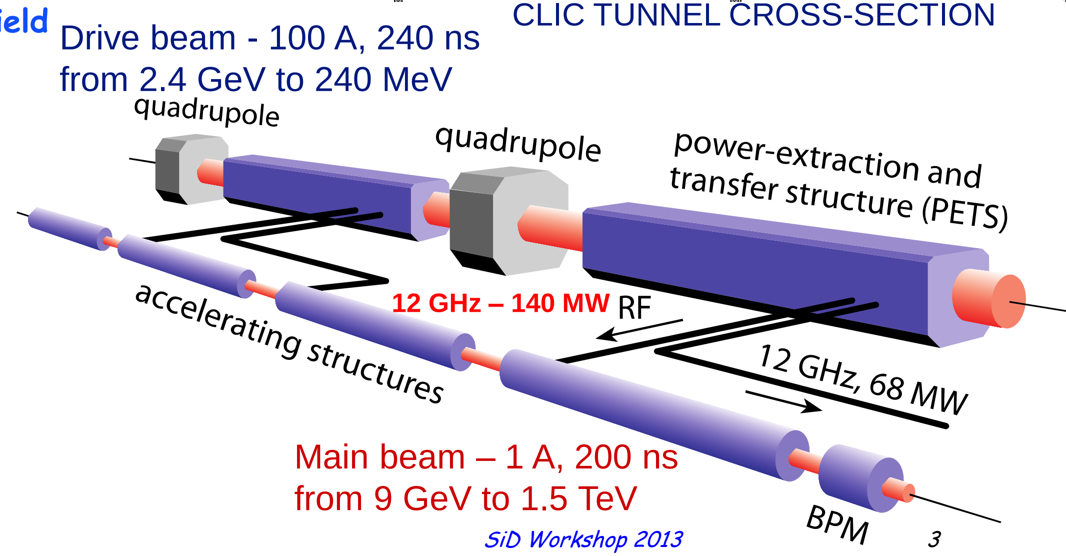
- **Novel Two-Beam Acceleration Scheme**
  - **Cost effective, reliable, efficient**
  - **Single tunnel, no active power components**
  - **Modular, staged energy upgrade**



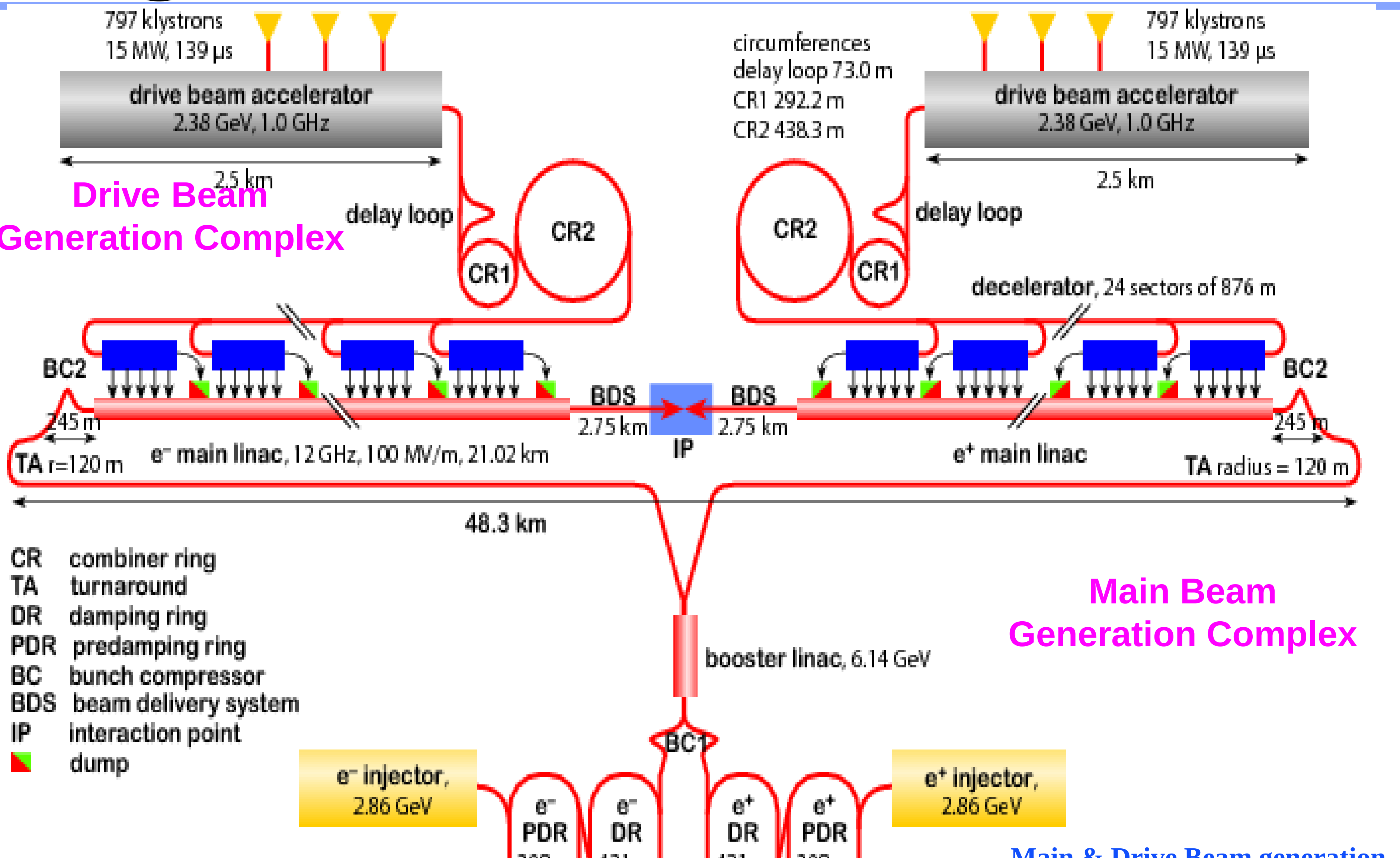
CLIC TUNNEL CROSS-SECTION

Compact rf pulses: by e- compression





CLIC layout 3 TeV



Main & Drive Beam generation complexes not to scale

CLIC: Linear Collider collaboration

European Strategy priorities related to the Energy Frontier:

•LHC and LHC luminosity upgrades (until ~2030)

- Higgs and Beyond the Standard Model physics in long term programme

•BSM – does it show up at LHC at 14 TeV, 2015 onwards ?

- What are the best machines to access such physics directly post-LHC …. we don't know but we can prepare main options the next years towards next strategy update (~2018)
- Two alternatives considered; higher energy hadrons (HE LHC or VHE LHC), **or highest possible energy e+e- with CLIC**

•**ILC in Japan**, a possibility for exploring the Higgs in detail, starting at 250 GeV

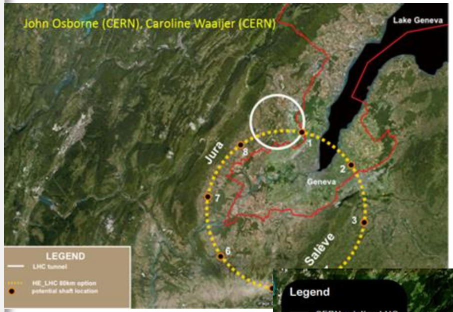
- If implemented a comprehensive programme that can map out the Higgs sector in particular

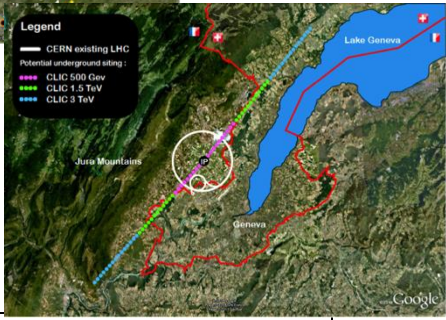
In accordance with this, pursue three connected activities in the period towards 2017-18 (when LHC results at nominal energy are becoming mature):

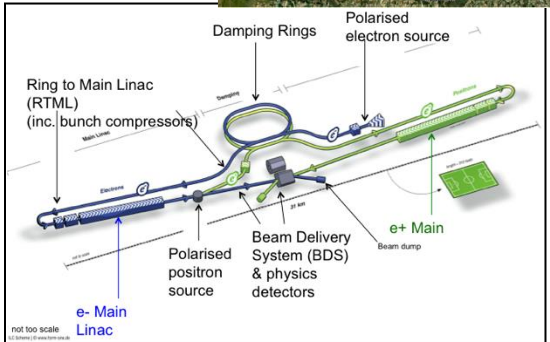
•**CLIC as option for the energy frontier (accelerator, det&phys studies)**

•ILC project development - towards a construction project

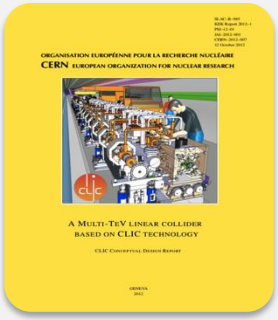
•Common activities wherever possible





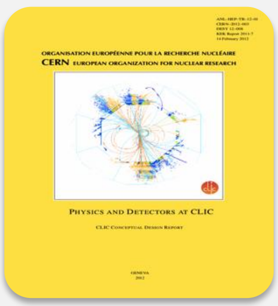


The CLIC CDR documents



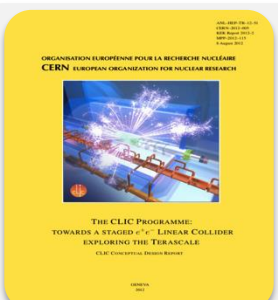
Vol 1: The CLIC accelerator and site facilities

- CLIC concept with exploration over multi-TeV energy range up to 3 TeV
- Feasibility study of CLIC parameters optimized at 3 TeV (most demanding)
- Consider also 500 GeV, and intermediate energy range
- https://edms.cern.ch/document/1234244/



Vol 2: Physics and detectors at CLIC

- Physics at a multi-TeV CLIC machine can be measured with high precision, despite challenging background conditions
- External review procedure in October 2011
- http://arxiv.org/pdf/1202.5940v1



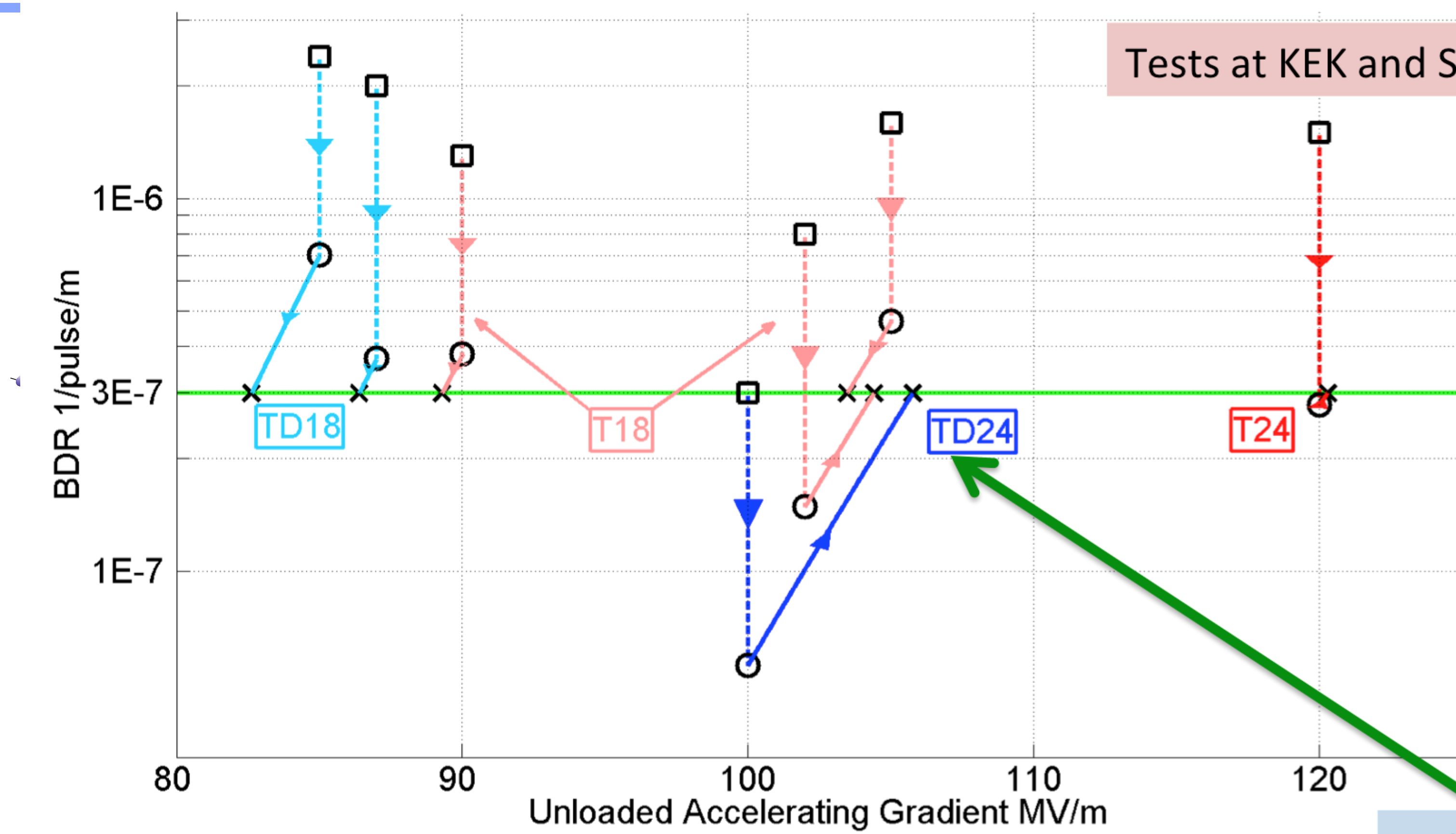
Vol 3: "CLIC study summary"

- Summary and available for the European Strategy process, including possible implementation stages for a CLIC machine as well as costing and cost-drives
- Proposing objectives and work plan of post CDR phase (2012-16)
- http://arxiv.org/pdf/1209.2543v1

In addition a shorter overview document was submitted as input to the European Strategy update, available at: http://arxiv.org/pdf/1208.1402v1

An input document to Snowmass 2013 has also been submitted: http://arxiv.org/abs/1305.5766

Conclusion of the accelerator CDR studies



Measurements scaled according to

$$p \propto G^{30} \tau^{5}$$

Unloaded 106MV/m
With loading 0-16% less

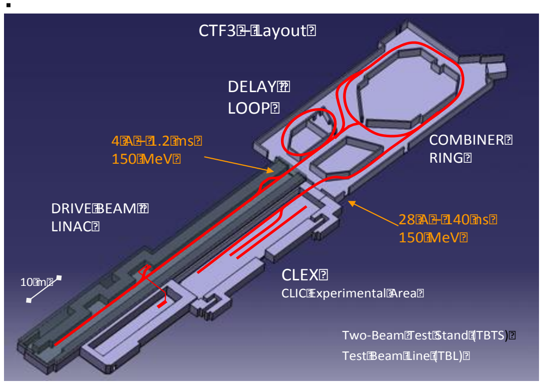
	Simple early design to get started	More efficient fully optimised structure
No damping waveguides	T18	T24
Damping waveguides	TD18	TD24 = CLIC goal

RF Team

Possible CLIC Timeline

2012-18 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.



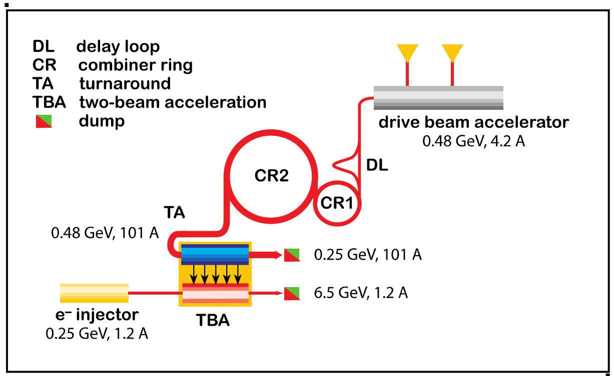
2018 Decisions

On the basis of LHC data and Project Plans (for CLIC and HiE LHC variants in particular), take decisions about next project(s) at the Energy Frontier.

2019-23 Preparation Phase

Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

Prepare detailed Technical Proposals for the detector-systems.



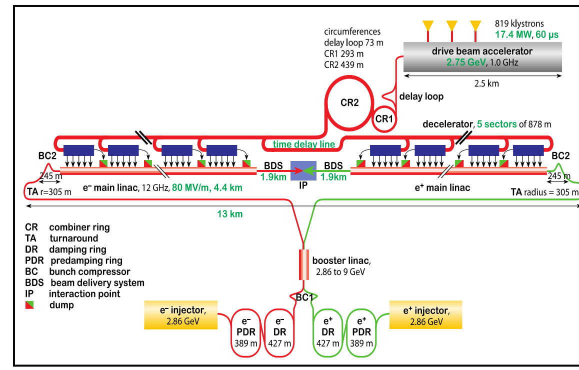
2023-24 Construction Start

Ready for full construction and main tunnel excavation.

2023-2030 Construction Phase

Stage 1 construction of a 500 GeV CLIC, in parallel with detector construction.

Preparation for implementation of further stages.

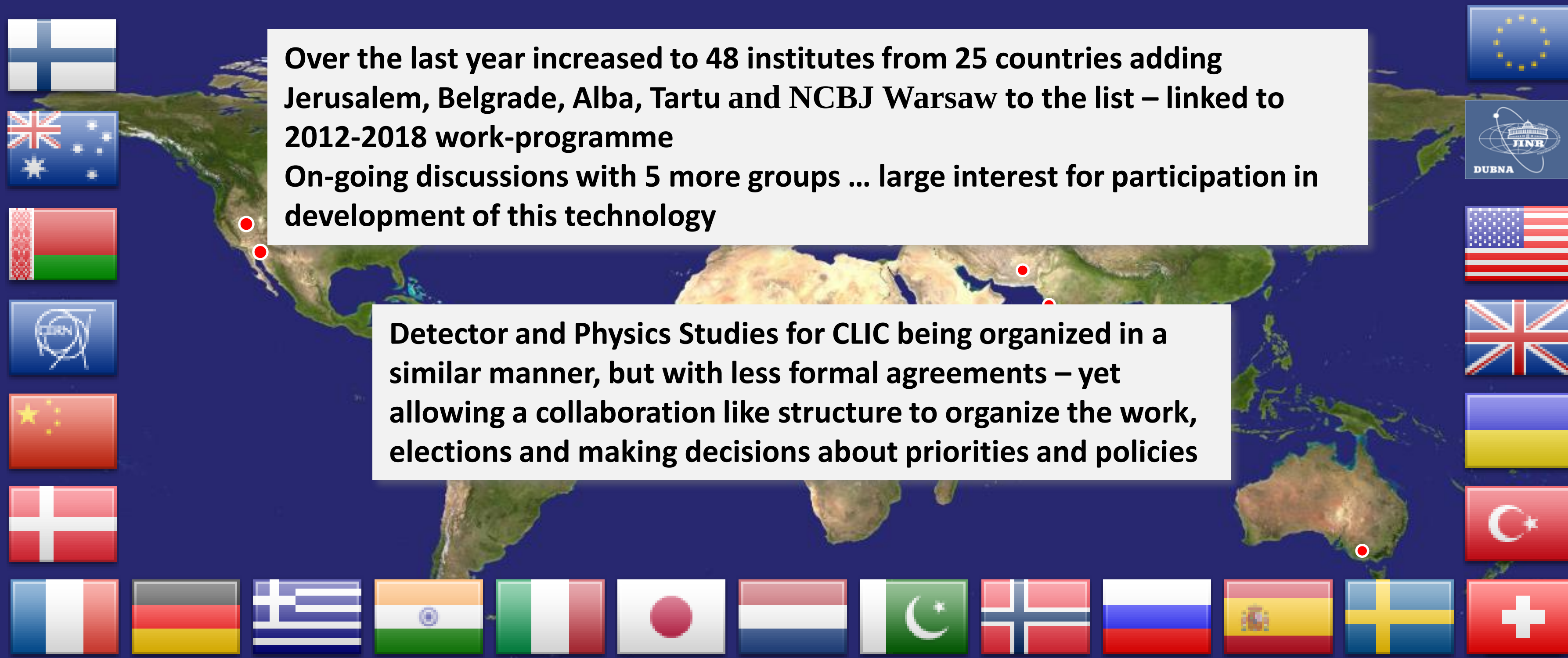


2030 Commissioning

From 2030, becoming ready for data-taking as the LHC programme reaches completion.

The CLIC Collaboration

CLIC multi-lateral collaboration - 48 Institutes from 25 countries



Over the last year increased to 48 institutes from 25 countries adding Jerusalem, Belgrade, Alba, Tartu and NCBJ Warsaw to the list – linked to 2012-2018 work-programme
On-going discussions with 5 more groups … large interest for participation in development of this technology

Detector and Physics Studies for CLIC being organized in a similar manner, but with less formal agreements – yet allowing a collaboration like structure to organize the work, elections and making decisions about priorities and policies

ACAS (Australia)
Aarhus University (Denmark)
Ankara University (Turkey)
Argonne National Laboratory (USA)
Athens University (Greece)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
ETH Zurich (Switzerland)
FNAL (USA)
Gazi Universities (Turkey)
Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
IHEP (China)
INFN / LNF (Italy)
Instituto de Fisica Corpuscular (Spain)
IRFU / Saclay (France)
Jefferson Lab (USA)
John Adams Institute/Oxford (UK)
Joint Institute for Power and Nuclear Research SOSNY /Minsk (Belarus)
John Adams Institute/RHUL (UK)
JINR
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NIKHEF/Amsterdam (Netherland)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Patras University (Greece)
Polytech. Univ. of Catalonia (Spain)
PSI (Switzerland)
RAL (UK)
RRCAT / Indore (India)
SLAC (USA)
Sincrotrone Trieste/ELETTRA (Italy)
Thrace University (Greece)
Tsinghua University (China)
University of Oslo (Norway)
University of Vigo (Spain)
Uppsala University (Sweden)
UCSC SCIPP (USA)

CLIC status

The period 2012-2018

X-band activites

CLIC Accelerator Activities 2012-18

An optimised machine:

- Higgs mass scale known and much improved cost and power models allow significant optimization
- Re-baselining studies ongoing (~375 GeV, ~1.5 TeV, 3 TeV) – including klystron based part, to be prepared for the optimal implementation strategy
- Overall design and system optimisation, technical parameters for all systems
- Cost, power/energy optimisation, scheduling, site including specific developments/studies

System tests:

- Studies of drive-beam stability and RF units, beam-loading experiments, deceleration, RF power generation and two beam acceleration with complete modules, as well as beam based alignment/beam delivery system/final focus studies
- CTF3+ programme
- ATF, FACET for luminosity performance and various other smaller programmes for specific technology developments
- Continuing/increasing links to light source community related to low emittance rings and X-band based FELs design studies

Energy reach:

- Linked to X-band technology development and industrialisation
- Increase test-capacity (several sites)
- Detailed studies and optimisation of all the critical RF elements (main structures the most central) as well as further industrialisation

Luminosity performance:

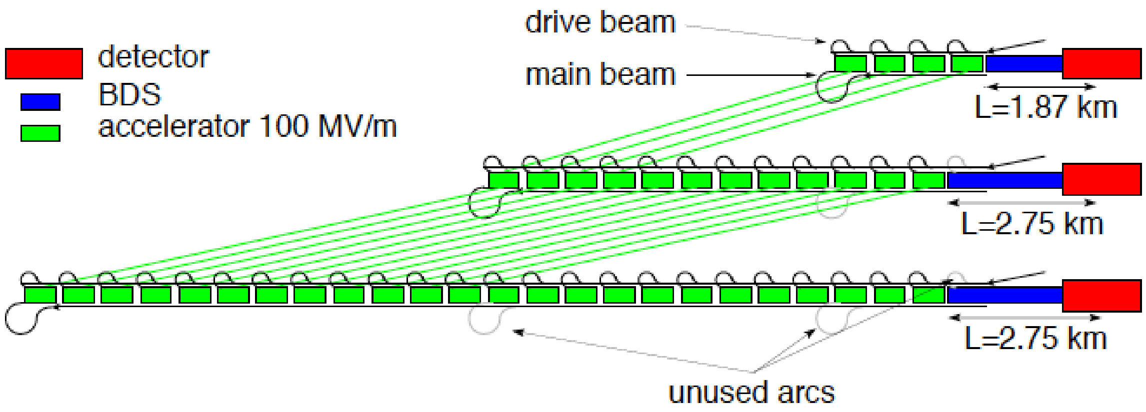
- Overall performance simulation and optimisation of each system – in some case linked to experimental benchmarking and/or tests (some examples below)
- Damping ring designs including experimental development and studies
- Main linac alignment and stability, wakefield studies, BBA alignment
- Final focus optimisation and studies
- Overall performance, reliability, robustness and risk studies

Technical developments:

- Critical elements, for performance, costs or power consumption, industrial developments or as needed for systemtest (some examples below)
- Module development including complete modules (RF, alignment/stability, magnets, instrumentation, vacuum, cooling, controls) for lab and CTF3
- RF power systems development (1 GHz)
- Alignment and stability methods and hardware

Rebaselining: Goals for Next Phase

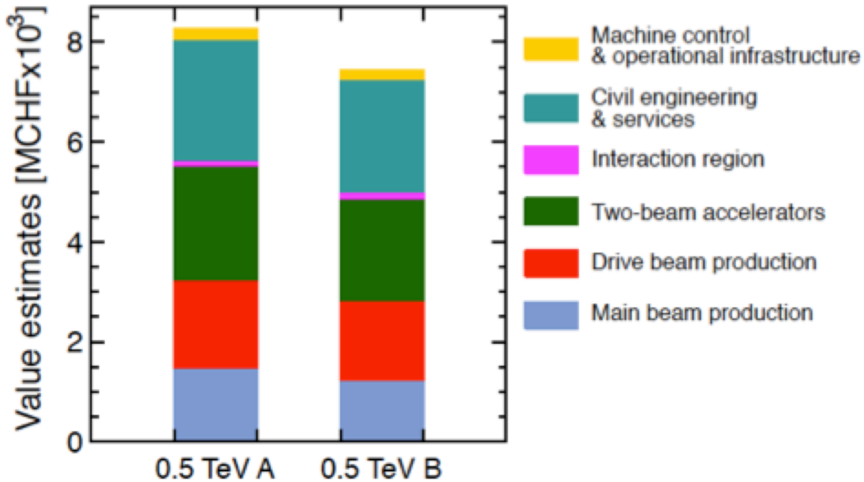
- Iterate on energy choices
  - Stage optimised for 375GeV for Higgs and top
  - 1-2TeV depending on physics findings, will still also do Higgs
  - 3TeV as current ultimate energy, includes more Higgs
- Focus on optimisation of first energy stage
  - But consider upgrades



- Identify, review and implement cost and power/energy saving options
  - Identify and carry out required R&D
- Re-optimise parameters (global design)
  - Develop an improved cost and power/energy consumption model
  - Iterations needed with saving options
- Study alternatives
  - E.g. first stage with klystrons

- Need to remain flexible, since we are waiting for LHC findings
  - But have some robustness of specific solutions and can anticipate this to some extent

Cost/power reductions : some identified savings



First to second stage: 4 MCHF/GeV (i.e. initial costs are very significant)

Caveats:

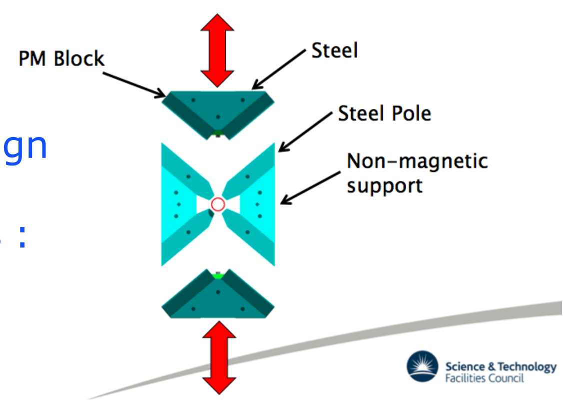
Uncertainties 20-25%

Possible savings around 10%

However – first stage not optimised (work for next phase), parameters largely defined for 3 TeV final stage

- Use of **permanent or hybrid magnets** for the drive beam (order of 50’000 magnets)
- Increase **drive beam accelerator** peak klystron power (has been underestimated) and increase L-band tube efficiency > 70%
- Electron **pre-damping ring** can be removed with good electron injector
- Dimension drive beam accelerator building and infrastructure are for 3TeV, **dimension to 1.5TeV results in large saving**
- Potential to use **cheaper material** for the drive beam accelerator structures
- Systematic **optimization** of injector complex linacs in preparation
- Power consumption:
  - Optimize and reduce overhead estimates

Permanent magnet design for the decelerators :



L-band klystron optimization studies :

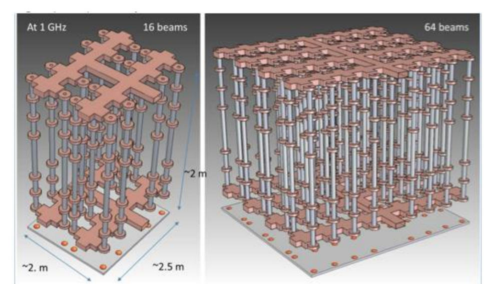


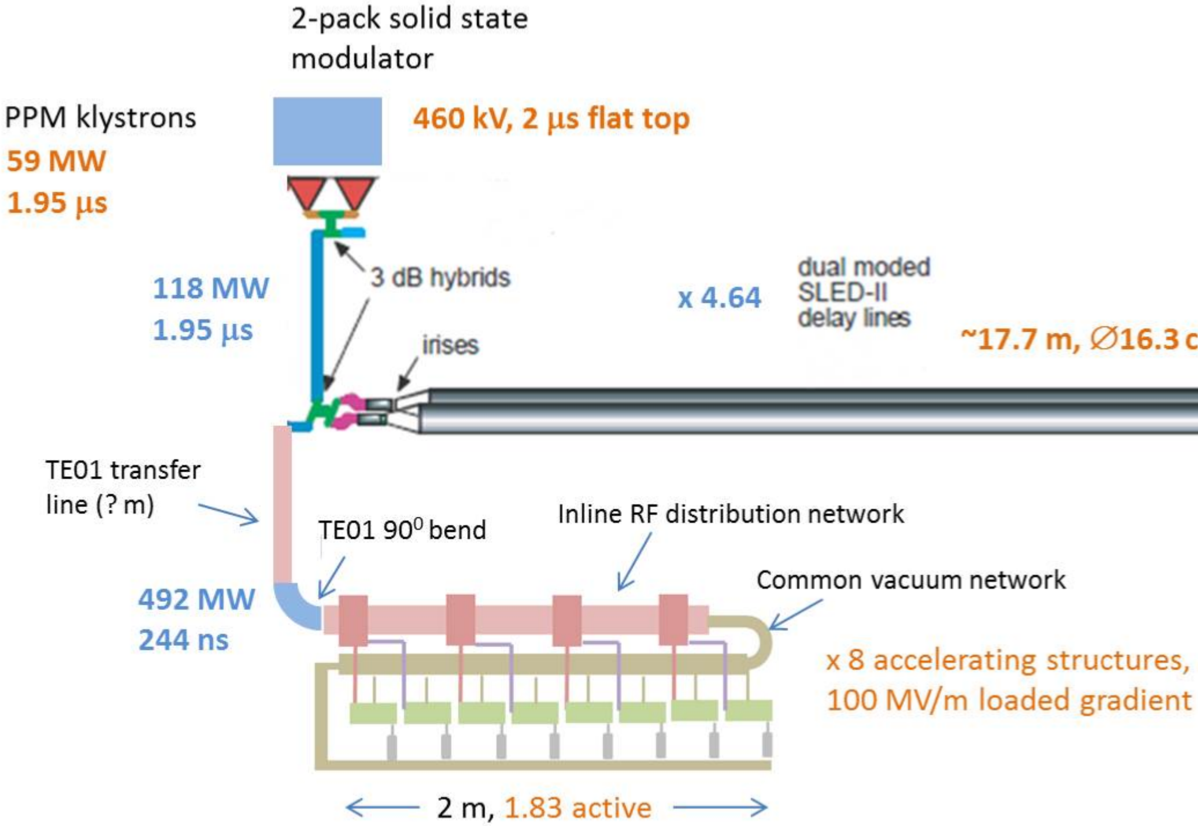
Figure 18: The clustered klystrons with ‘most compact’ RF distribution network [13].

Study of Klystron-based CLIC

Only interesting for first energy stage
Would need ~30,000 klystrons at 3TeV

Simple parametric cost study has shown that nominal structure CLIC_G is very good for klystron-based approach
Can use the same structure for drive beam and klystron-based

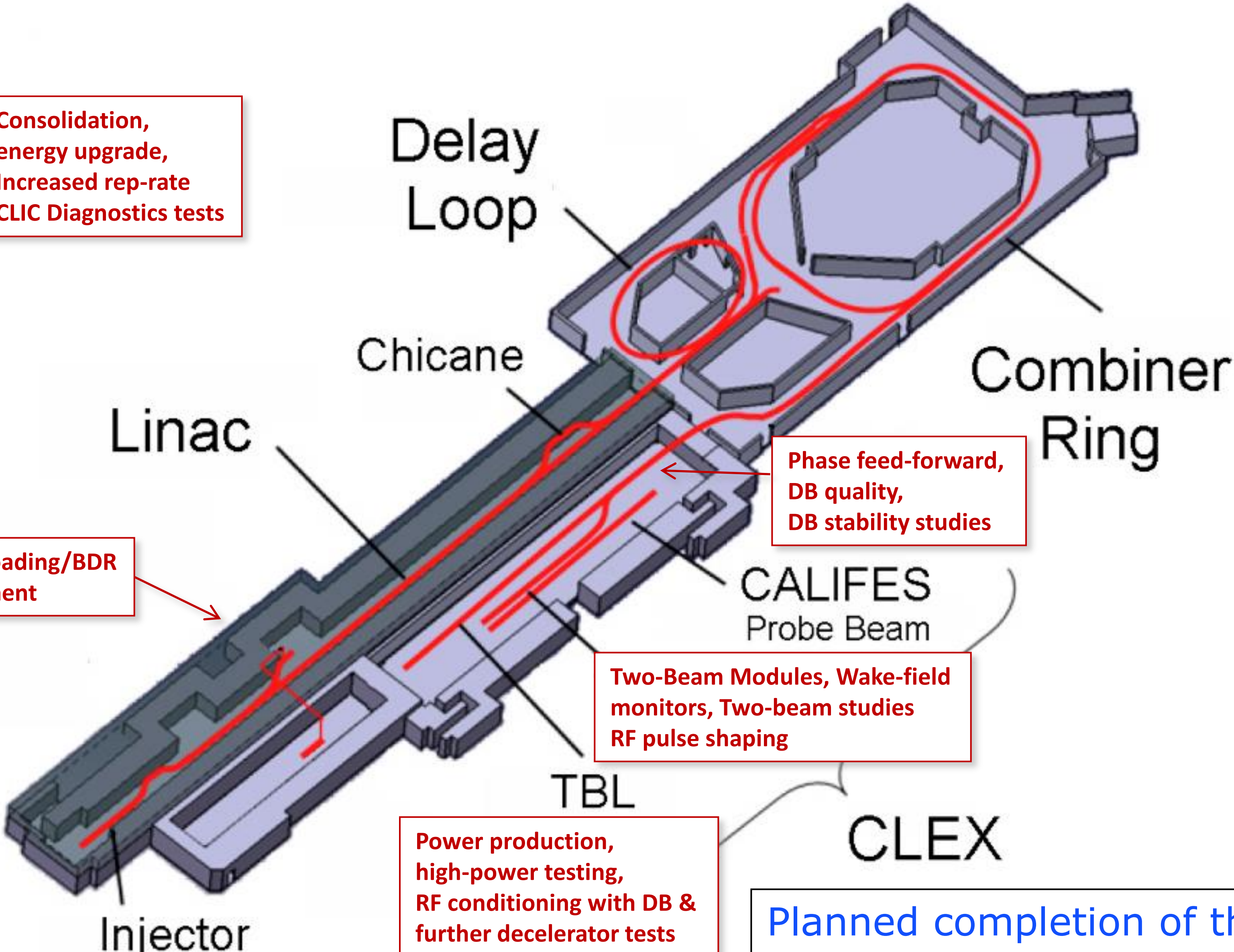
Linac energy overhead	10%
Linac filling factor	≈ 0.75
Number of klystrons	4484
Number of structures	17936
Active length/single linac	2.242 km
Length/single linac:	3 km
bunches/pulse	312
particles/bunch	$3.72 \cdot 10^9$
repetition rate	50 Hz
Luminosity	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$



Defined RF unit based on this structure and achieved klystron performances

A simplified-model cost comparison shows similar cost for 500 GeV klystron-based CLIC as 500 GeV drive beam CLIC.

CLIC Test Facility (CTF3)



Consolidation,
energy upgrade,
Increased rep-rate
CLIC Diagnostics tests

Beam loading/BDR experiment

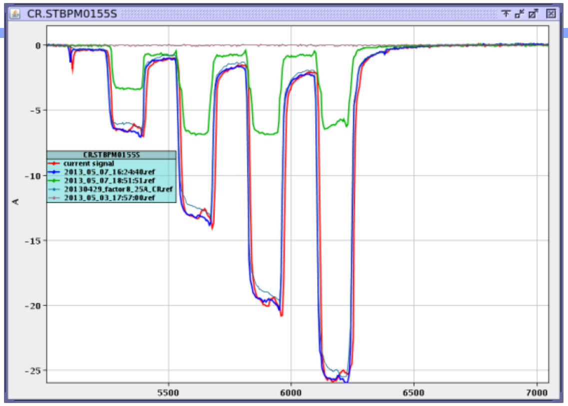
Phase feed-forward,
DB quality,
DB stability studies

Two-Beam Modules, Wake-field monitors, Two-beam studies
RF pulse shaping

Power production,
high-power testing,
RF conditioning with DB &
further decelerator tests

Planned completion of the CTF3 program: end 2016

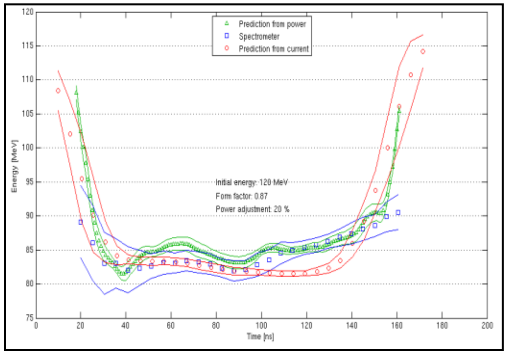
CTF3: recent results and plans



- Operation with **8 times combination** now routine
- New feedbacks added to improve phase stability

Goal is to achieve

- $\varepsilon_x = \varepsilon_y \cong$ 150 µm also for factor 8, currently ε_x=550µm due to orbit error
- Charge stability $\sigma_Q \approx 10^{-3}$ for factor 8



- **Deceleration increased from 30% to 35%**
- Decelerator BPM prototype tested (stripline, LAPP)
- Good understanding of the optics

Goal is to reach 40% deceleration

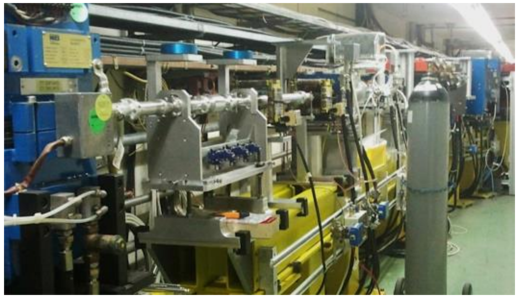
Feed-forward to correct drive beam phase

Phase monitors successfully tested

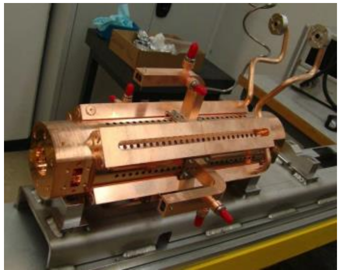
Goal:

- Install kickers and amplifiers (FONT5) in 2013
- First tests in autumn

INFN Frascati
JAI/Oxford



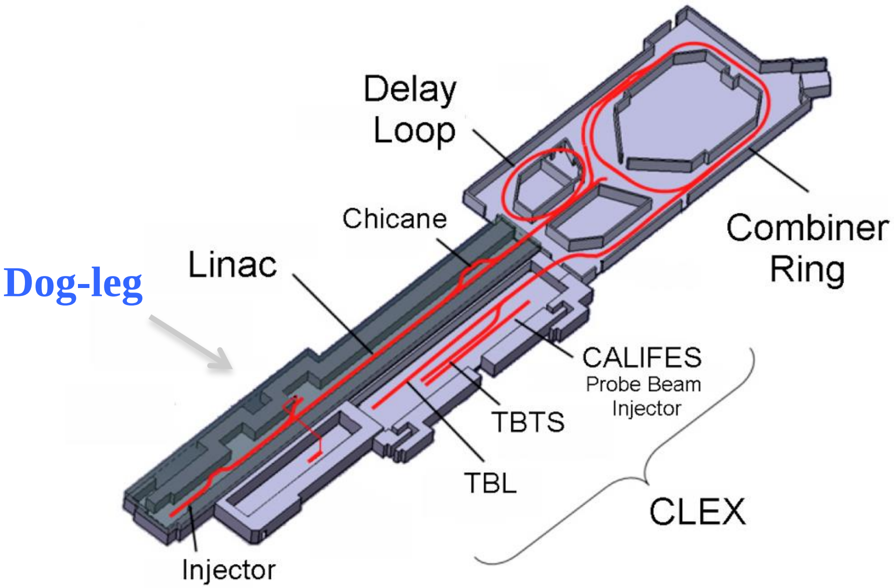
- Structure with **wakemonitor** installed in TBTS
- Resolution (required: 3.5 um) is being tested

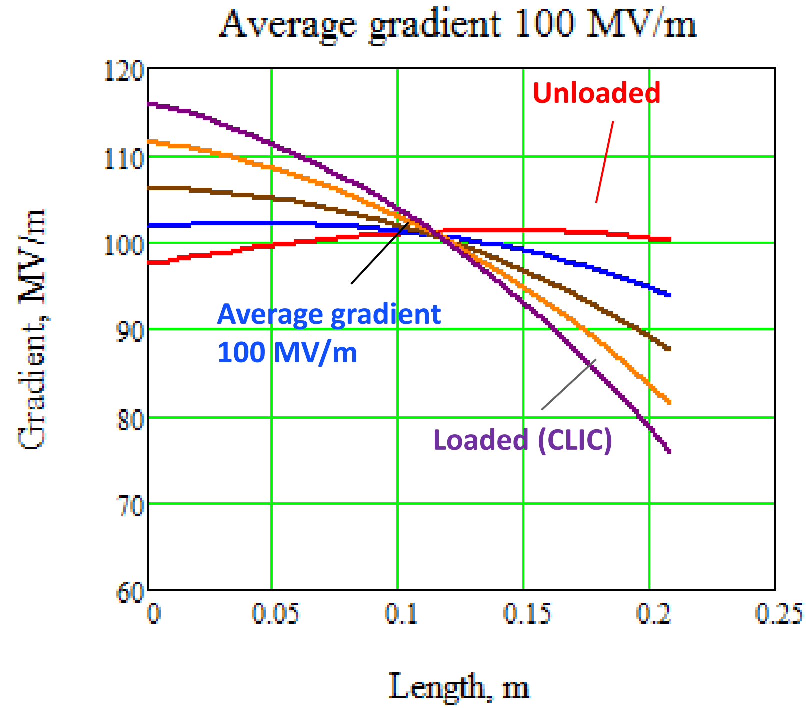


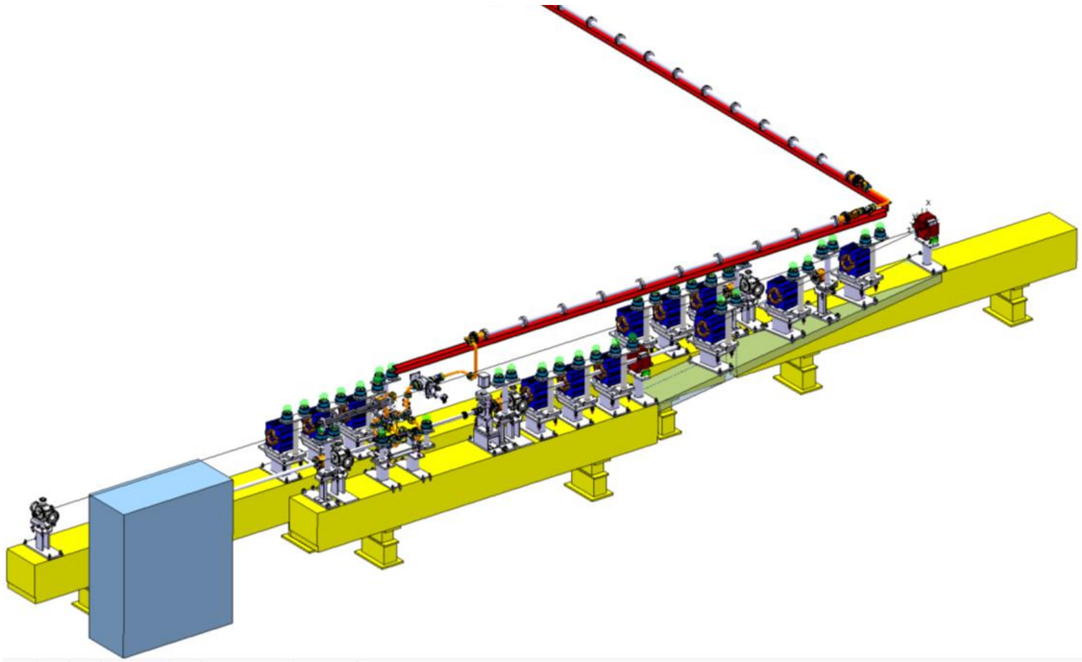
CEA IRFU - Saclay

- **1 GHz klystron test stand**, with gun and sub-harmonic buncher planned

Beam Loading Test Facility



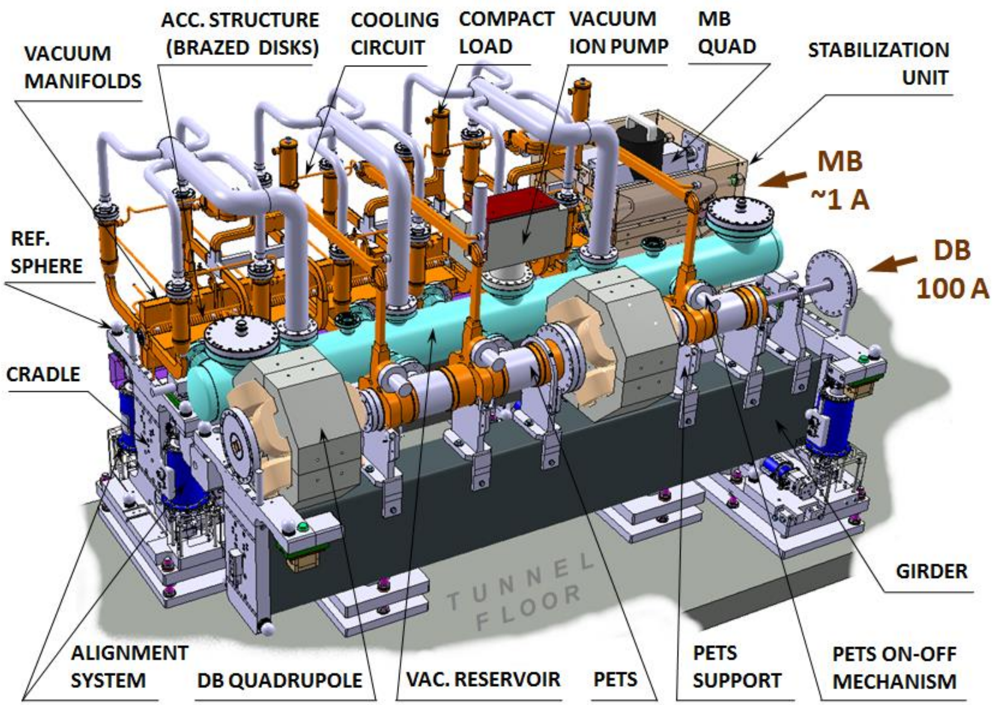


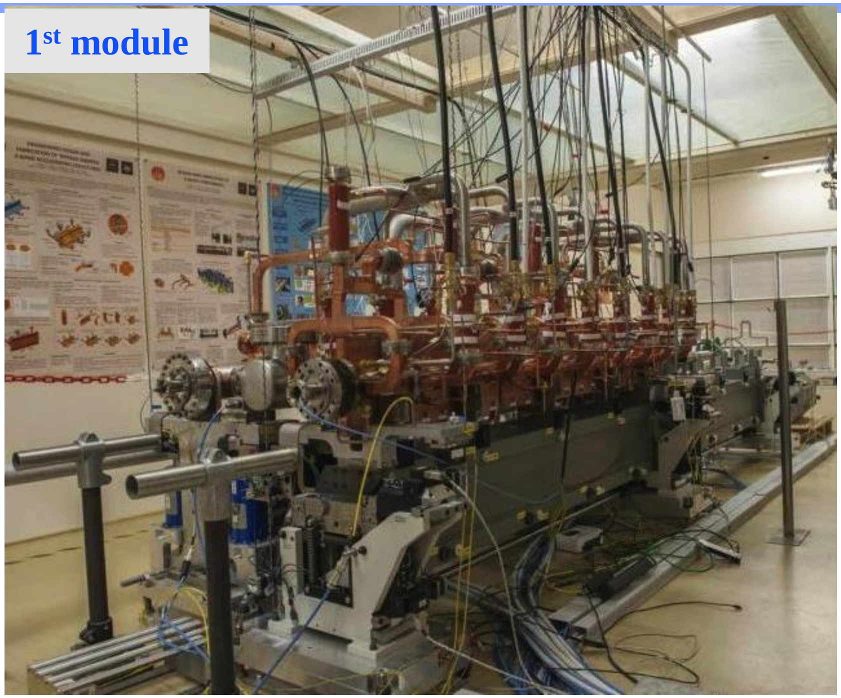


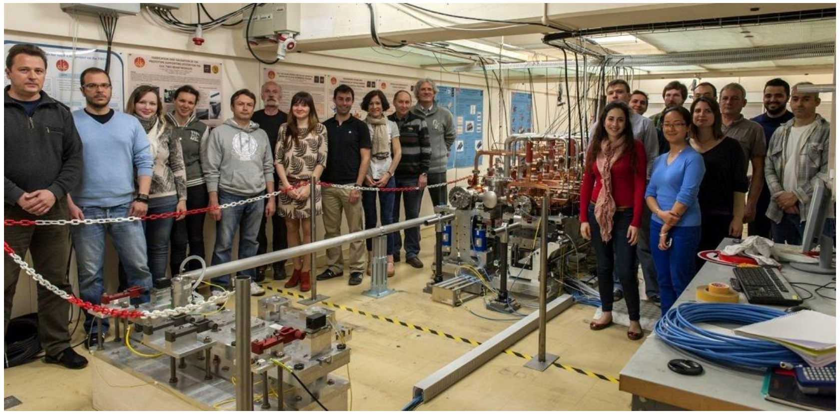
Test stand in CTF3 dog-leg to test gradient with **beam loading**

- Structure powered at full power with 12 GHz klystron
- 1 A drive beam sent through structure
- System begin commissioned
- Conditioned structure to come this year

CLIC Two-beam Module







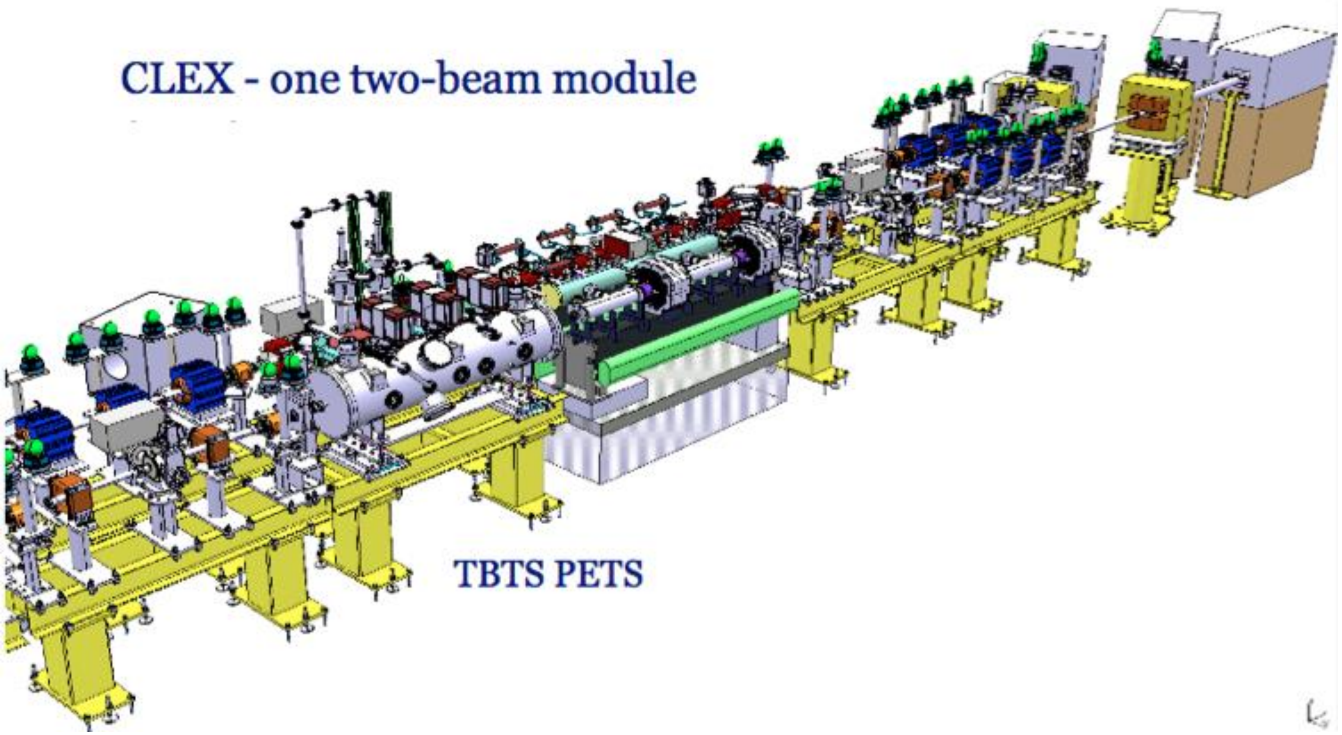
G. Riddone, Module Team

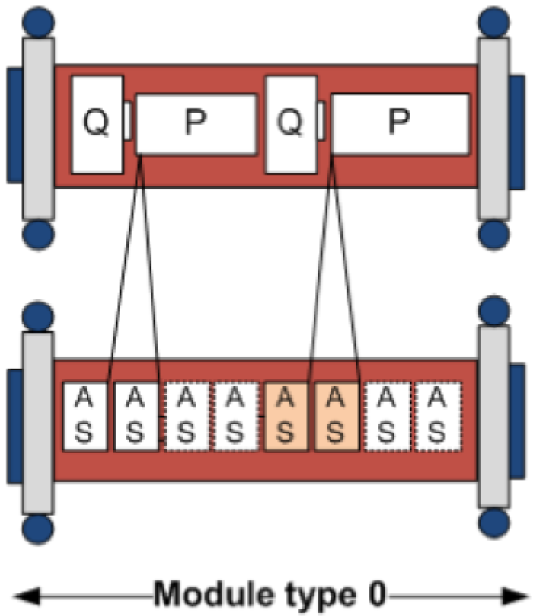
Complete test modules:

- **First laboratory CLIC module completed**
- All safety measures implemented (power dissipation ~7 kW per module)
- DAQ and control system
- (Labview based) tested and validated
- First tests promising and in line with FEA simulations

CTF3 Two-beam Module

A Two-Beam Module with full rf functionality planned to be installed in CTF3



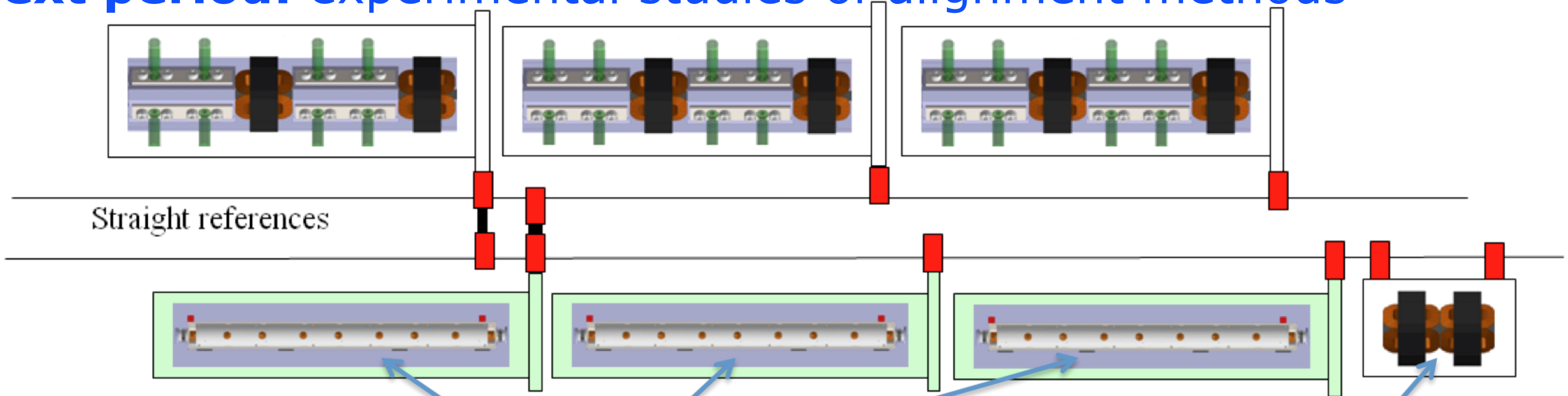


Will provide validation of the CLIC module functionality with rf and beams

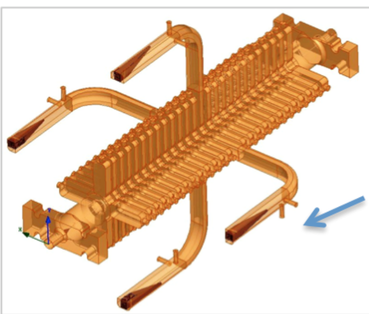
Main Linac Alignment

Emittance preservation feasibility for LC: mainly simulation studies.

Next period: experimental studies of alignment methods

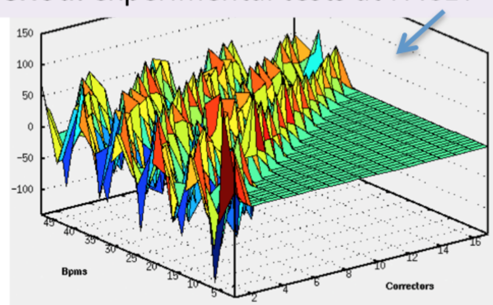


1) Pre-align BPMs+quads
accuracy O(10µm) over about 200m and
Stabilize quadrupole O(1nm) @ 1Hz
Next period: dedicated research test stand



3) Use wake-field monitors
accuracy O(3.5µm).
Next period: improved design and testing in the CLIC Test Facility.

2) Beam-based alignment
Next period: experimental tests at FACET

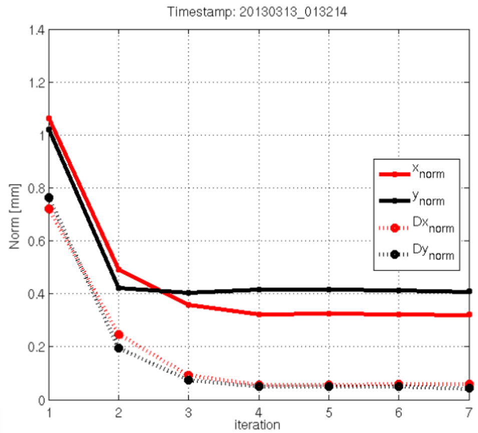


CLIC Beam-Based Alignment tests at FACET

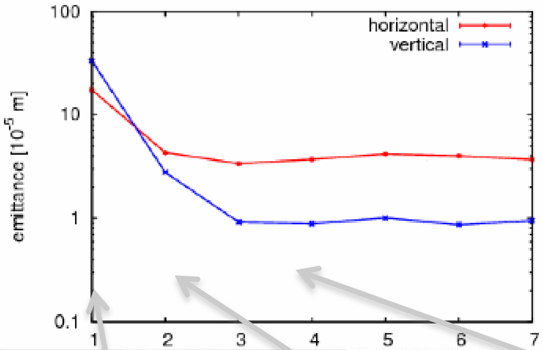
A. Latina,
J. Pfingstner,
E. Adli,
D. Schulte

Dispersion-free Steering (DFS) proof of principle – March 2013

Orbit/Dispersion



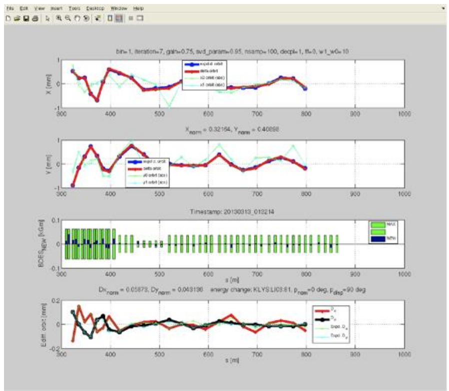
Emittance

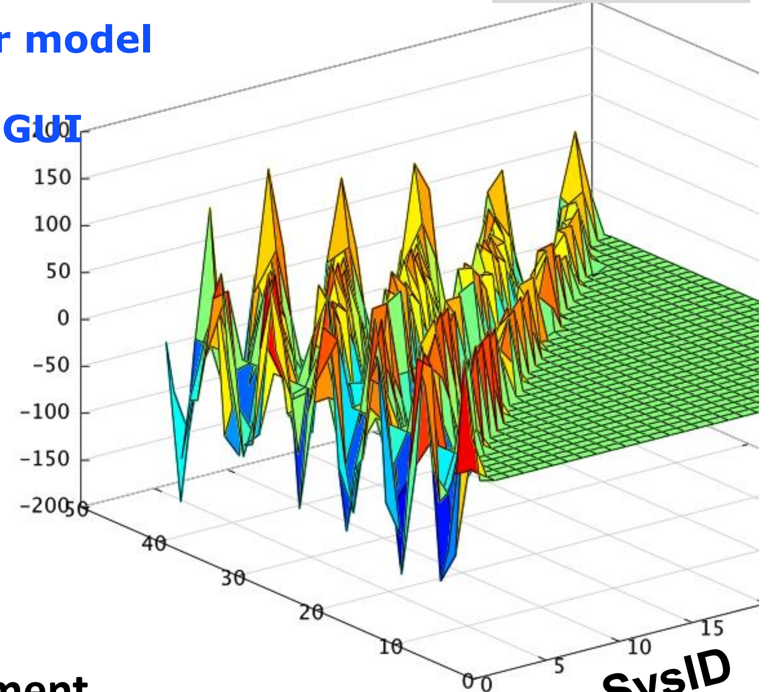


DFS correction applied to 500 meters of the FACET linac

- SysID algorithms for model reconstruction
- DFS correction with GUI
- Emittance growth is measured

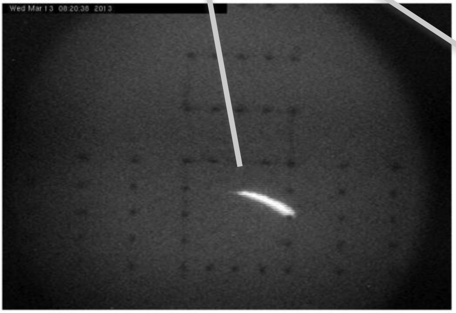
Graphic User Interface:



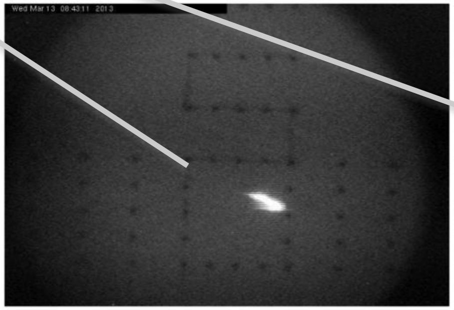


SysID

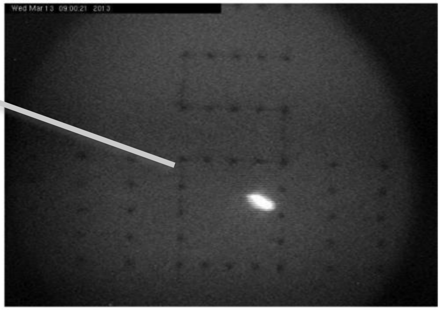
Beam profile measurement



Before correction



After 1 iteration



After 3 iterations

Incoming oscillation/dispersion is taken out and flattened; emittance in LI11 and emittance growth significantly reduced.

CLIC status

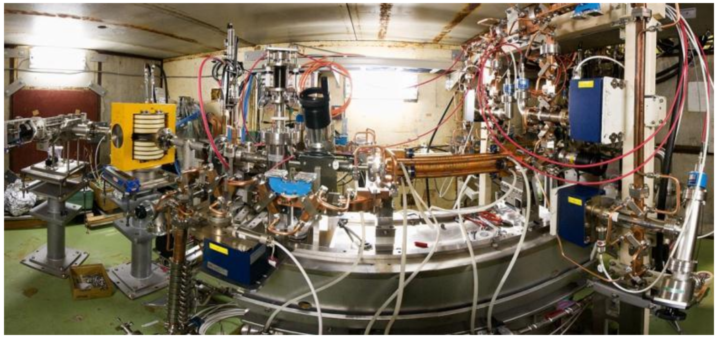
The period 2012-2018

X-band activites

12 GHz Test Stands for CLIC

Previous:
Scaled 11.4 GHz tests at SLAC and KEK.

NEXTEF at KEK

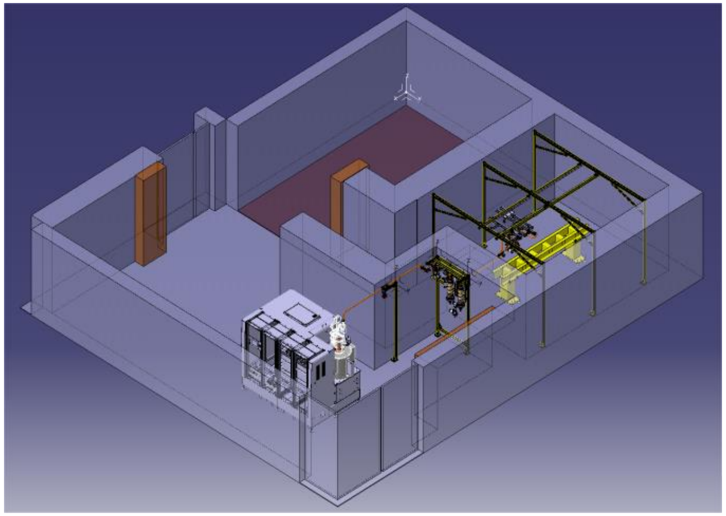


ASTA at SLAC

XBOX1 at CERN operational with SLAC klystron

100 MW can be provided in pulses of 250 ns, 50 Hz.
Can power two CLIC accelerating structures.

XBOX2 at CERN, industrial klystron should be ready this year



Planned capacity : power six CLIC accelerating structures

Next period: greatly increased X-band rf test capability, at 12 GHz, at CERN

Collaboration: CLIC X-band to FELs

New initiative**: CLIC X-band technology to FELs**

CERN does not do light sources
- It is not part of CERN's mandate

But use of X-band in FELs in other labs would help CLIC for a number of tasks
- Further technical developments with industry
  - Will create the industrial basis
- Performance studies of accelerator parts and systems
  - From components up to large scale main linac system test

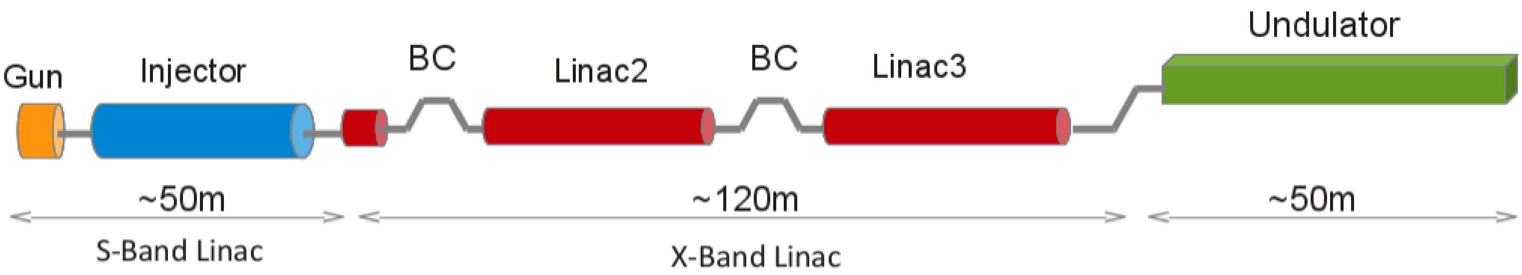
We think that FELs can profit from X-band technology
- For collaborators to judge based on further studies

CLIC will work with laboratories to build an FEL and help them as needed (including RF, instrumentation, alignment, beam dynamics, test stands, industrial contacts …)

Compact FEL : details

Collaboration **kick-off meeting**: D. Schulte, CERN, September 2013. Institutes from 5 countries present.

Looked a bit into a linac design for a typical Angstrøm FEL :



Proposal of Ch. Adolphsen et al. shows concept for X-band

E=6GeV Q=250pC σ_z=8µm ε≈400nm-500nm

Swiss FEL (C-band, approved):

E=5.8GeV Q=200pC σ_z=7µm ε≈200nm-500nm

As example we did chose Q=250pC, E=6GeV and will go for similar bunch lengths
Do not study injector (use the one from PSI for now) or undulator

Conclusions

- The CDR volumes document :
  - The feasibility studies for CLIC
  - A staged approach to implement the project

- Active and varied program for the next period :
  - **Rebaselining** is on the way with focus also on low energy
  - System tests (**modules**, test stands)
  - Stabilization and alignment demonstrations -> **luminosity reach**
  - Focus on **cost** and industrialization

- Collaborations are formed to promote the use of CLIC technology for other applications; **X-band technology maturity**

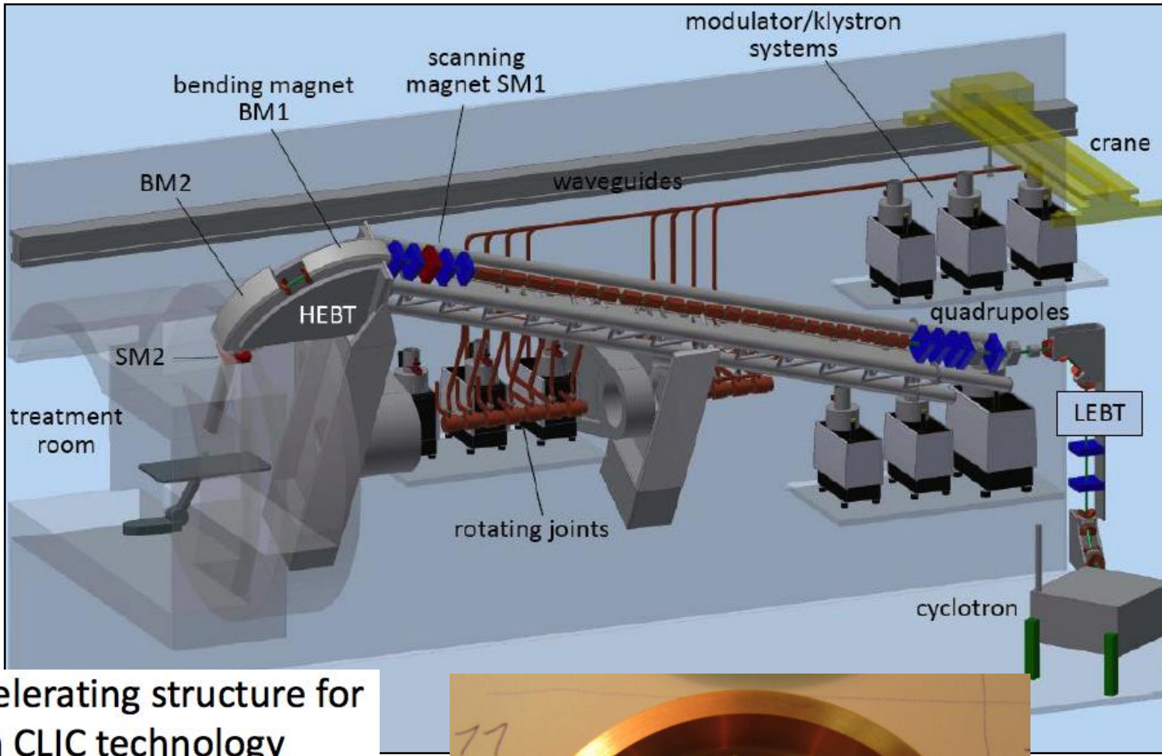
- **Thanks to the CLIC collaboration for the slides and work presented**

EXTRA

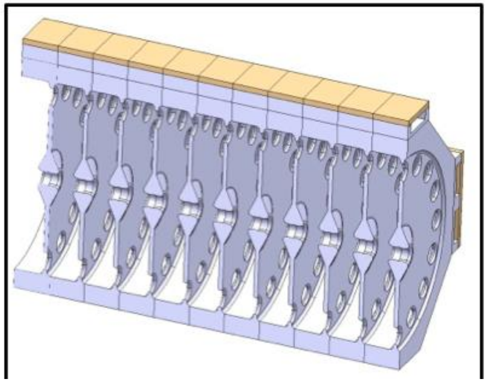
High-gradient hadron therapy structures

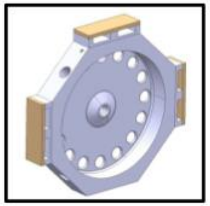
Technology transfer of CLIC high-gradient research to 3 GHz high gradient structures for **proton therapy** (TERA Tulip project).

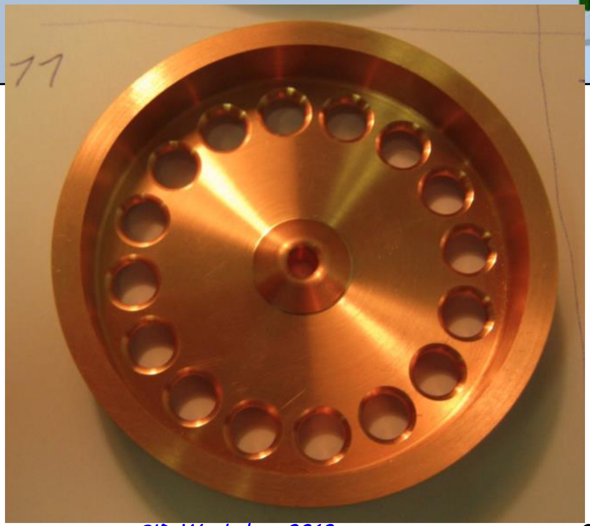
Increase the effective gradient in proton therapy linac structures (cyclinacs) to about **50 MV/m** (factor two).



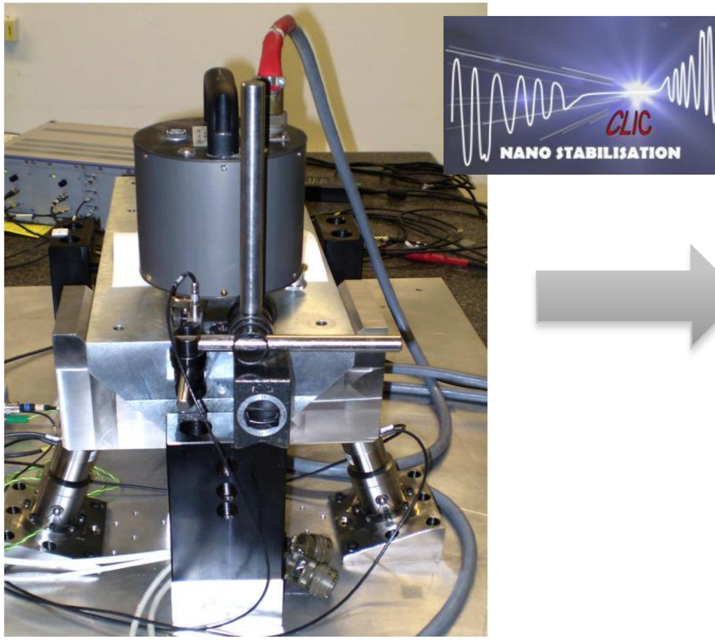
Backward wave high-gradient accelerating structure for proton acceleration based on CLIC technology

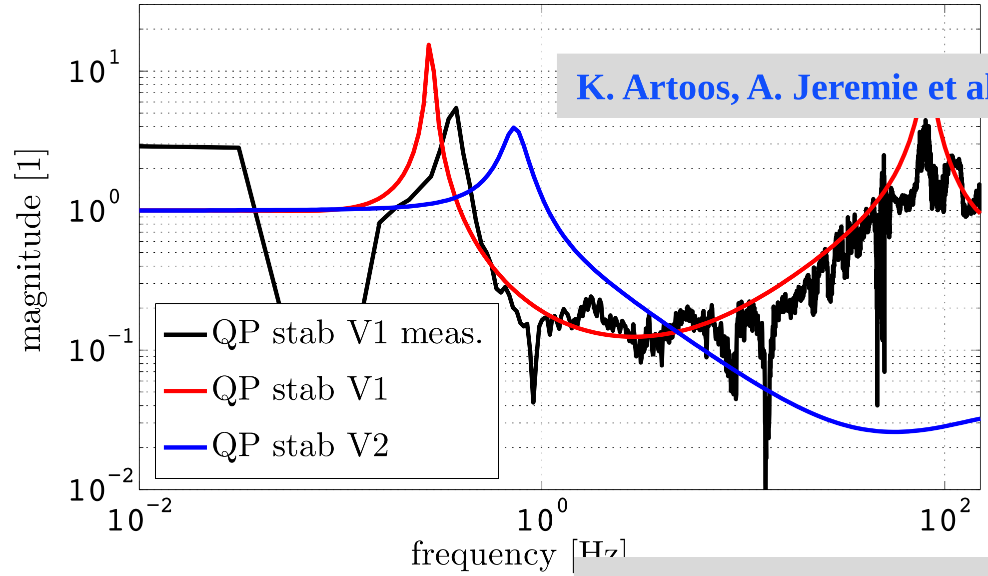




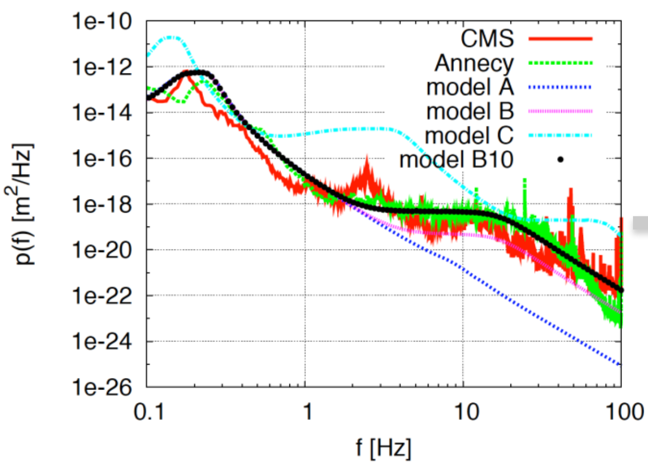


Active Stabilisation





K. Artoos, A. Jeremie et al.



Code

Machine model
Beam-based feedback

J. Pfingstner, J. Snuverink et al.

Luminosity achieved/lost

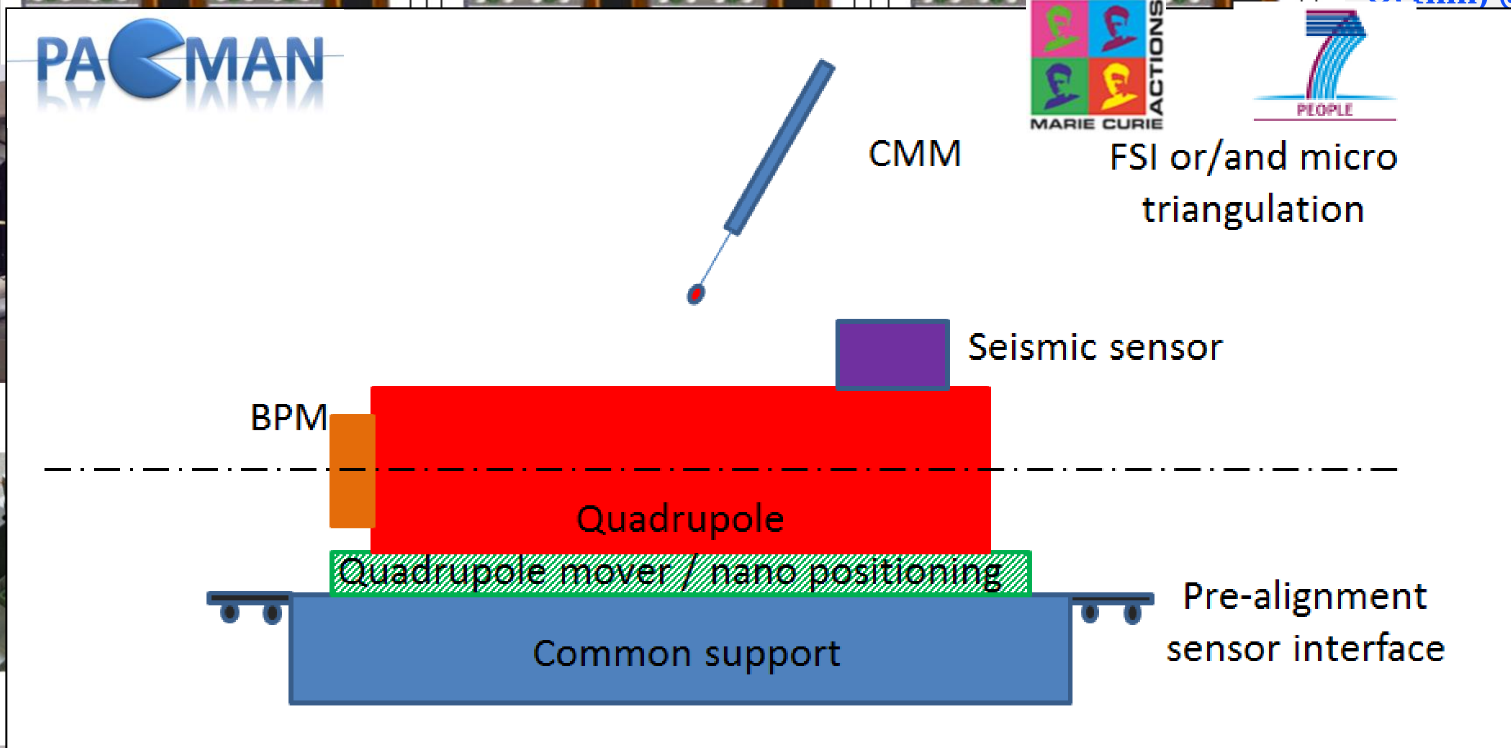
	B10
No stab.	53%/68%
Current stab.	~~108%/13%~~ 114%/7%
Future stab.	118%/3%

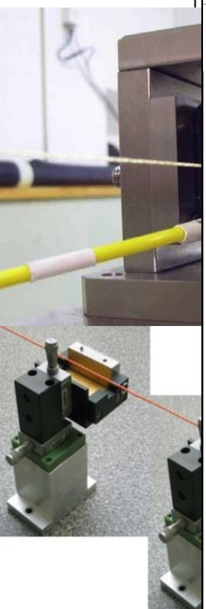
Close to/better than target

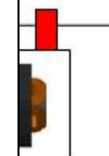
Main Linac Alignment

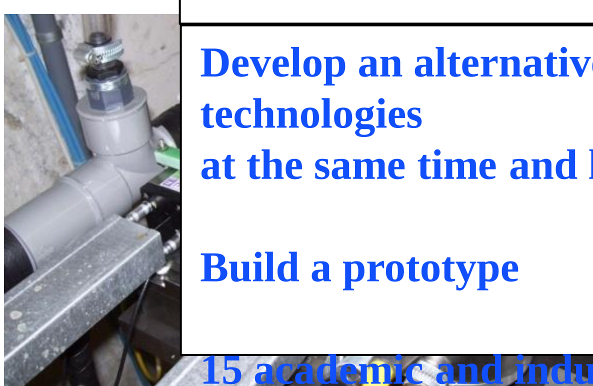
H. Mainaud Durand et al.

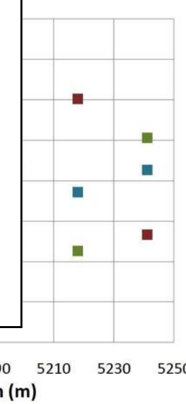
Stabilise quadrupole O(1nm) @ 1Hz









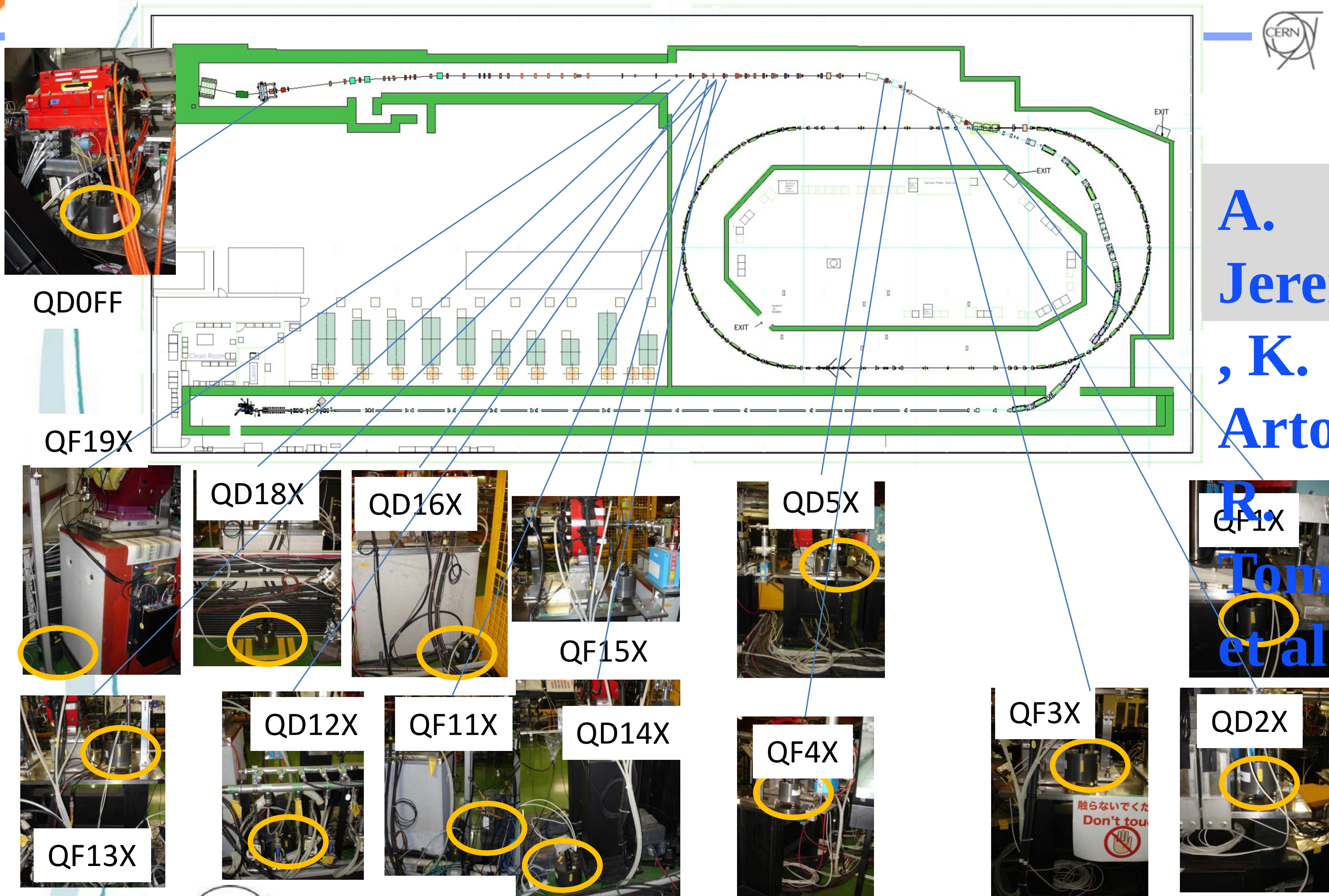


Develop an alternative solution integrating all the alignment steps and technologies at the same time and location (CMM machine)

Build a prototype

15 academic and industrial partners, EC funds 10 PhD students (Marie Curie)

Stabilisation Experiment



A. Jeremie, K. Artoos, R. Tomas et al.

A.Jeremie ATF2 operations meeting May 17 2013 3

D. Schulte, CLIC

CLIC High Gradient structure

High gradient limitations :

*** Surface magnetic field**

Pulsed surface heating ΔT => material fatigue => cracks

*** Field emission due to surface electric field**

RF break downs

Break down rate (BDR) => Operation efficiency,

Local plasma triggered by field emission => Erosion of surface

Dark current capture

=> Efficiency reduction, activation, detector backgrounds

BDR = f(max field, rf pulse length, freq) ~ $E_{acc}^{30} t_p^5$ (empirical)

*** RF power flow**

RF power flow and/or iris aperture apparently have a strong impact on achievable E_{acc} and on surface erosion. Mechanism not fully understood.

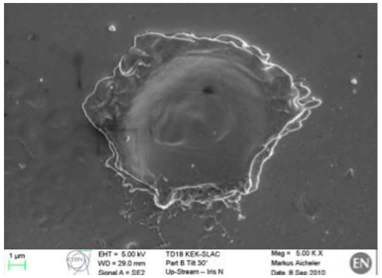
Numerical values for copper

$$\Delta T \approx 4\cdot 10^{-17}\left[\frac{\mathrm{K\,m^2}}{\mathrm{V^2}}\right]\sqrt{t_P\, f}\; E_{acc}^{\,2}$$

$$\Delta T_{max} \approx 50\,\mathrm{K}$$

$$t_P < \left(\frac{\Delta T_{max}}{4\cdot 10^{-17}}\right)^2 \frac{1}{f\, E_{acc}^{\,4}}$$

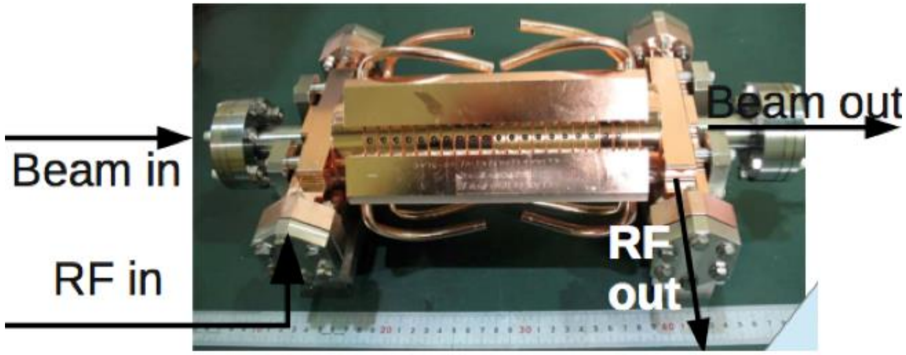
CLIC limit: ΔT < 50 K, limits pulse length to few 100 ns



Cu Surface after break down

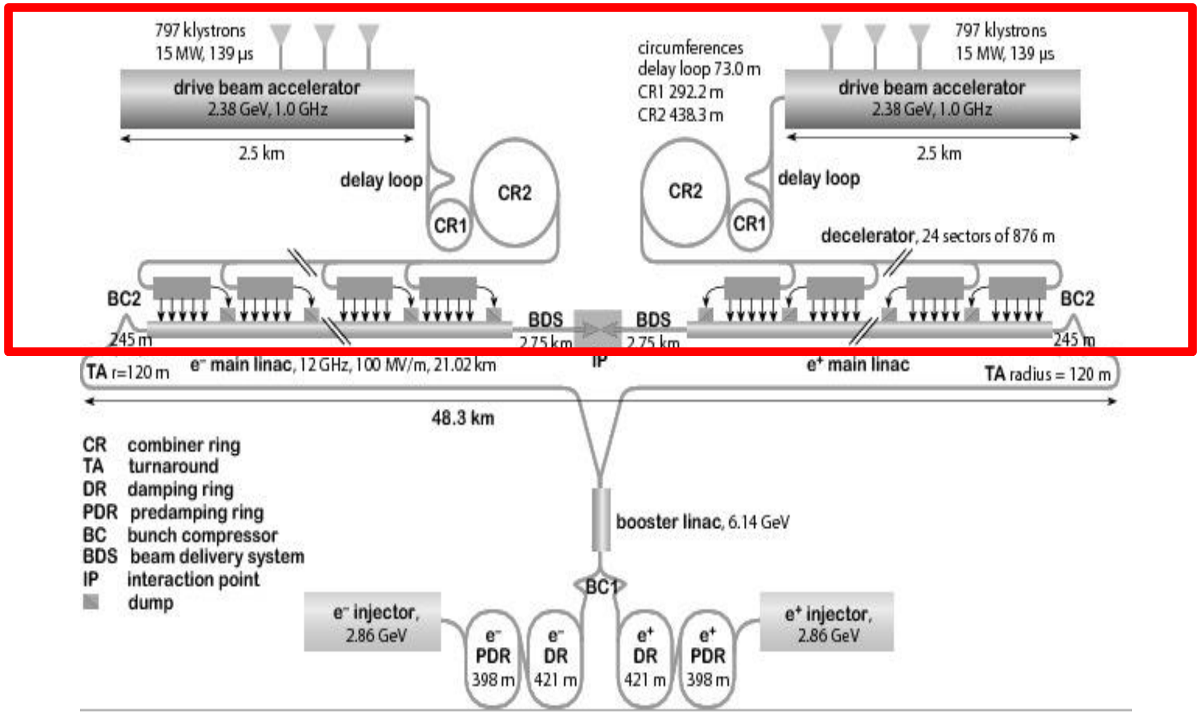
CLIC main linac structure :

- 12 GHz Cu TW
- 100 MV/m gradient (loaded)
- BDR < 3 x 10^{-7}/pulse/m
- Rf pulse length: $\mathbf{t_p = 240\ ns}$

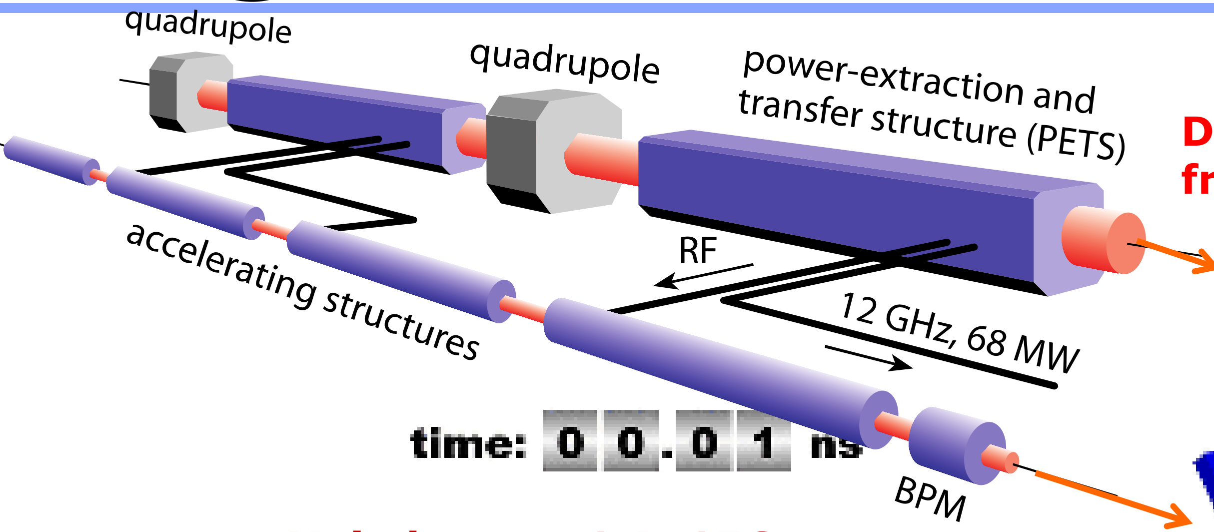


The CLIC drive beam rf power source

Unique for the CLIC two-beam acceleration scheme

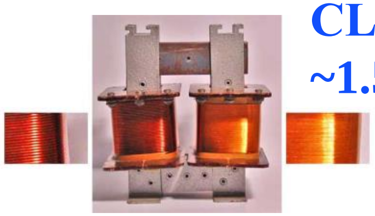


The CLIC Two-Beam scheme

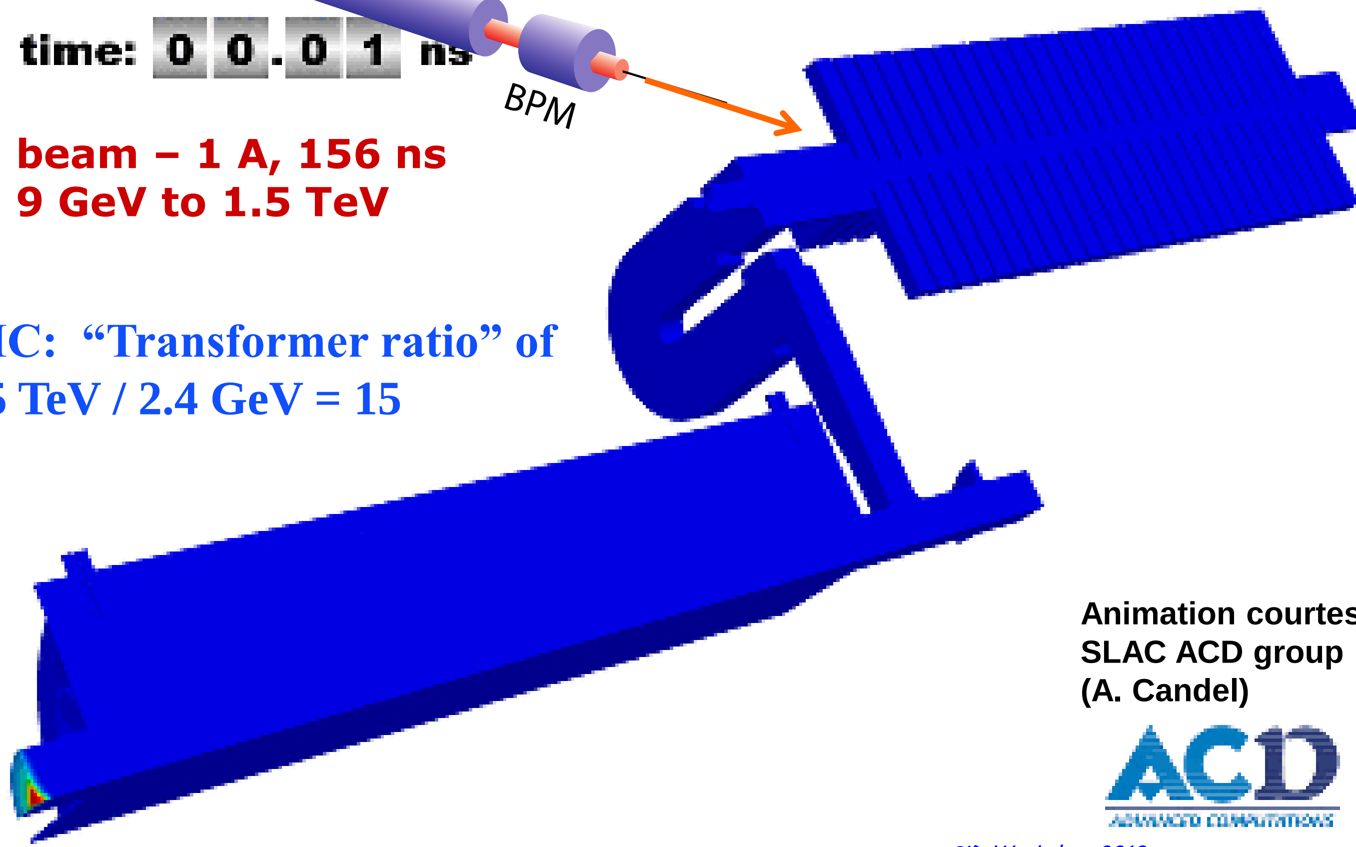


Drive beam - 101 A, 240 ns
from 2.4 GeV to 240 MeV

Main beam – 1 A, 156 ns
from 9 GeV to 1.5 TeV

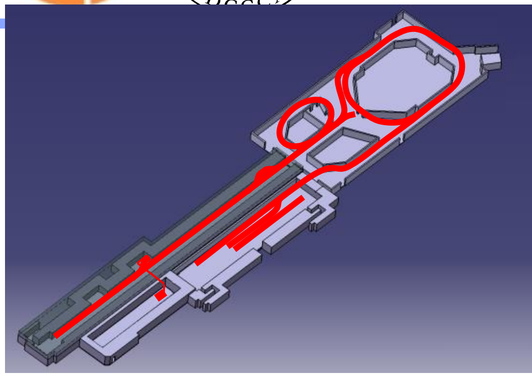


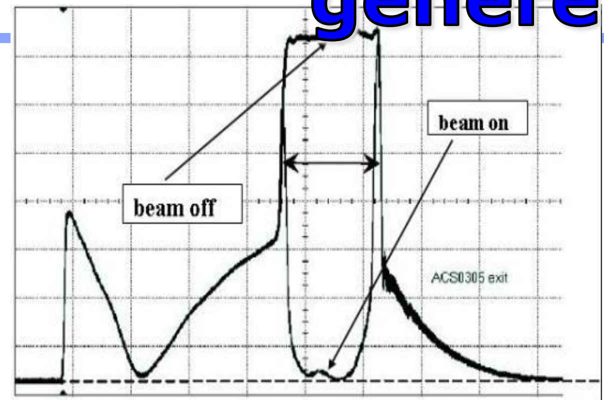
CLIC: "Transformer ratio" of
~1.5 TeV / 2.4 GeV = 15



Animation courtesy
SLAC ACD group
(A. Candel)

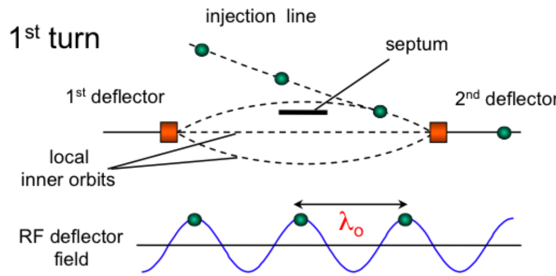
Milestones: drive beam genereration



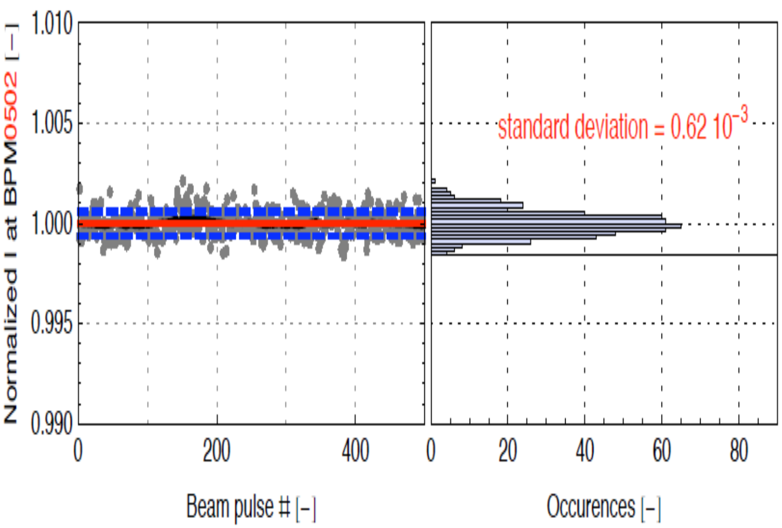


Fully loaded acceleration RF to beam transfer: 95.3 % measured. No issues found with transverse wakes in structures. **Operation is** routinely with full loading

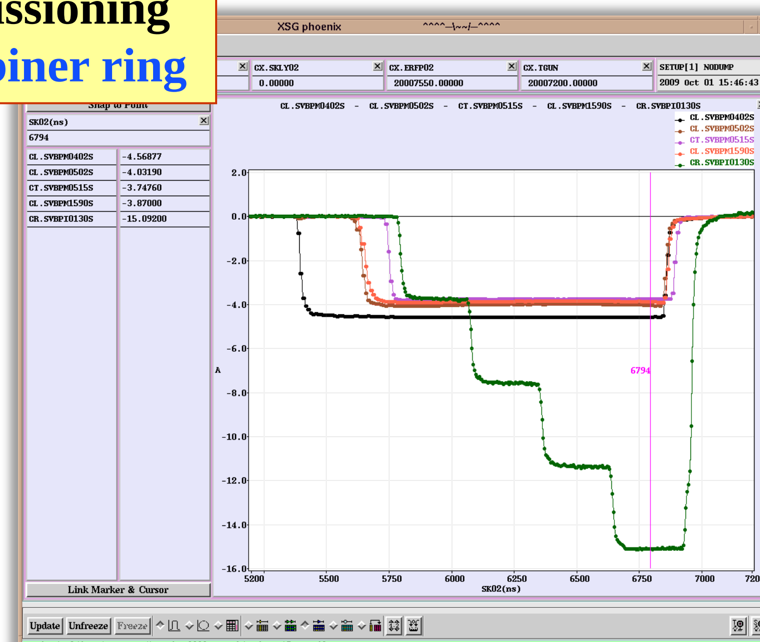
1.2 us drive beam pulse



Drive beam current stability at the end of the fully loaded linac : better than CLIC specification: 0.75 10^{-3}



Full commissioning of x 4 combiner ring

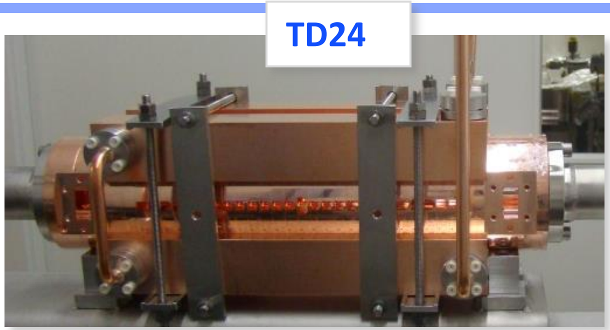


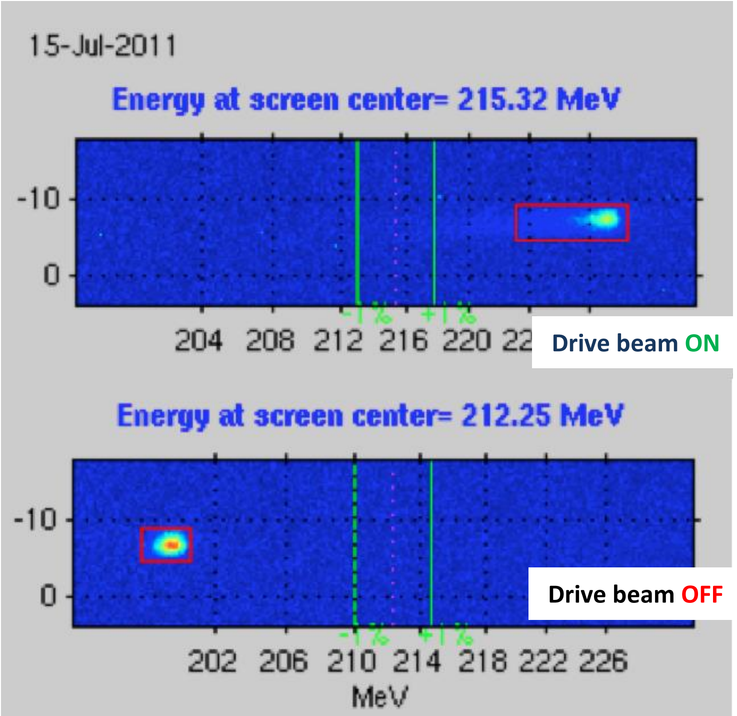
Two-beam Acceleration

Two-Beam Acceleration demonstration in TBTS

Up to 145 MV/m measured gradient

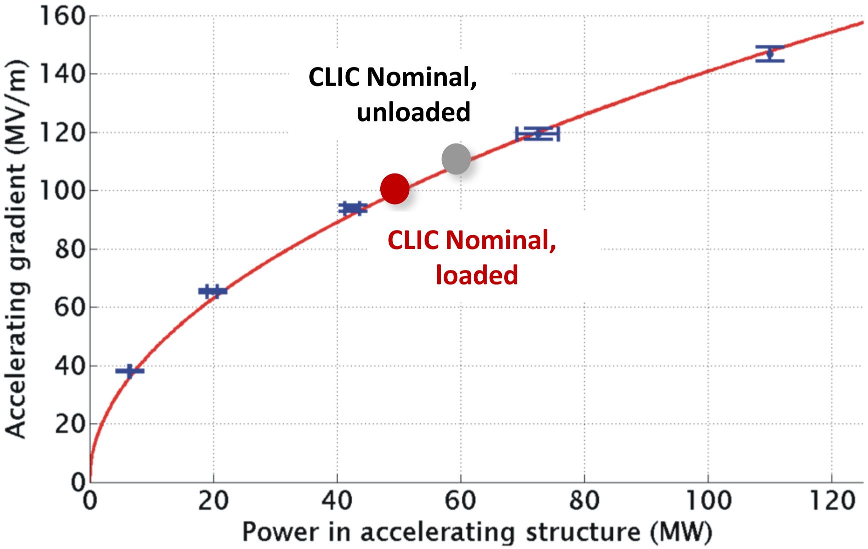
Good agreement with expectations (power vs. gradient)





Maximum stable probe beam acceleration measured: 31 MeV

⇒ Corresponding to a gradient of 145 MV/m

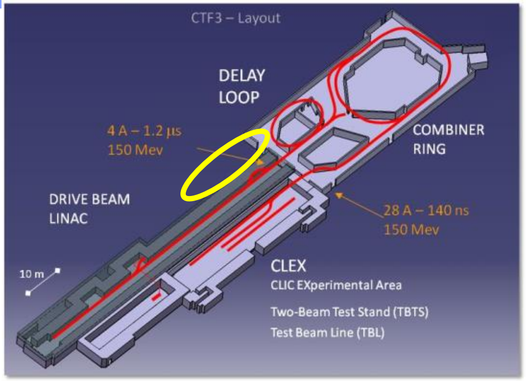


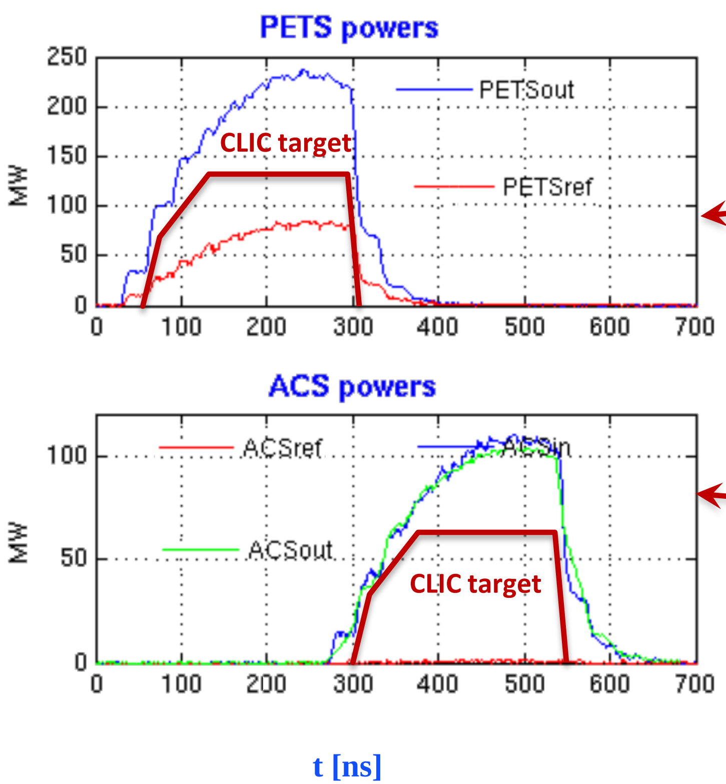
Power Production in TBTS

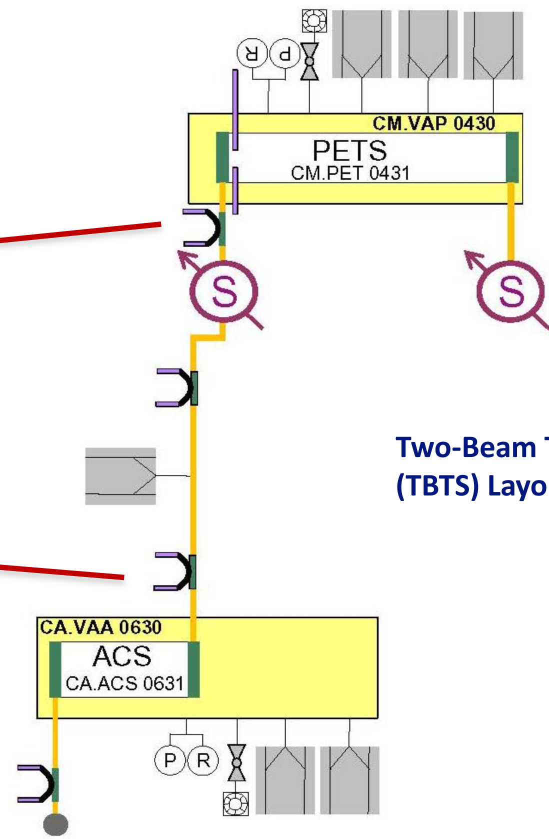
PETS operated routinely above **200 MW** peak RF power

providing reliably pulses ~ **100 MW** peak to accelerating structure.

About **twice** the power needed to demonstrate **100 MV/m** acceleration in a two-beam experiment with TD24 structure.



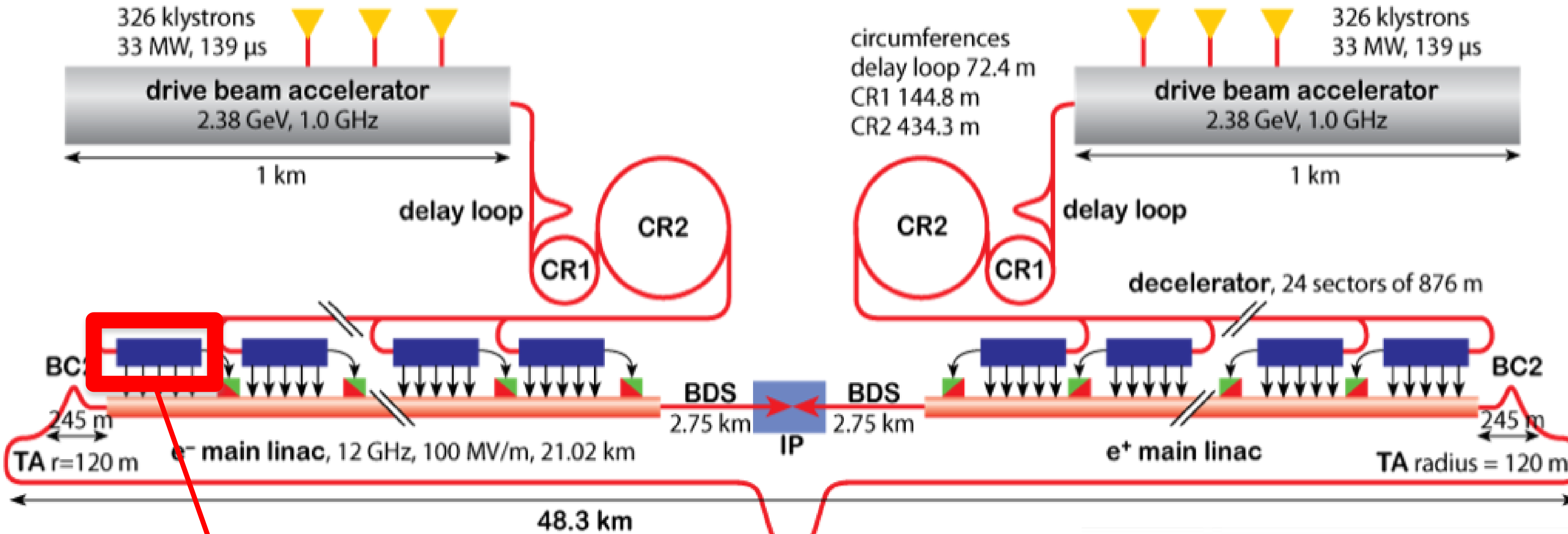


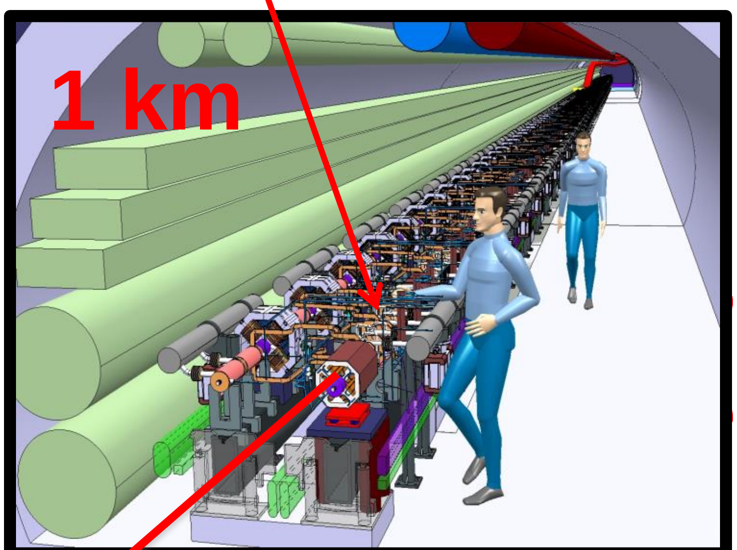


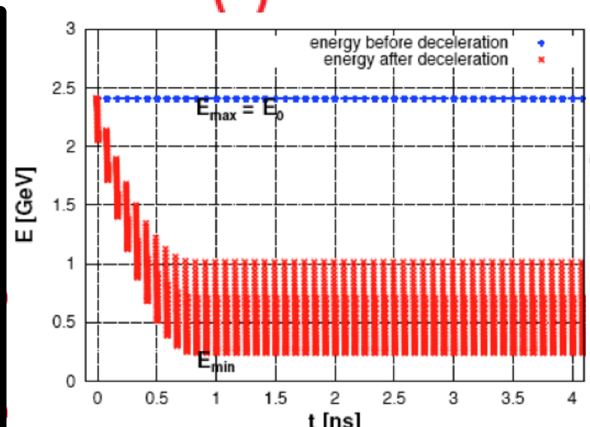
Two-Beam Test Stand (TBTS) Layout

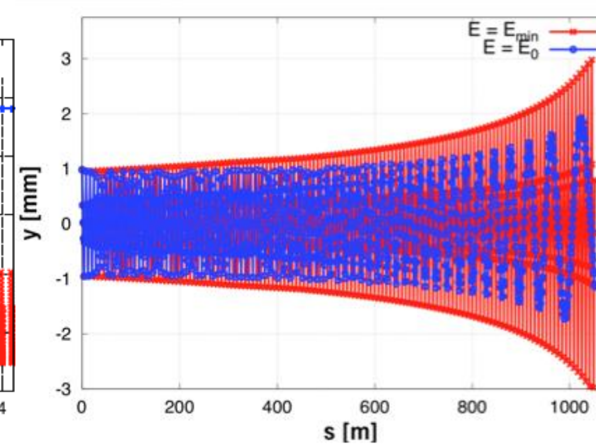
The CLIC decelerator

Decelerator: Transports the 101A, 2.4 GeV CLIC Drive Beam,extracting more than 80% of the energy





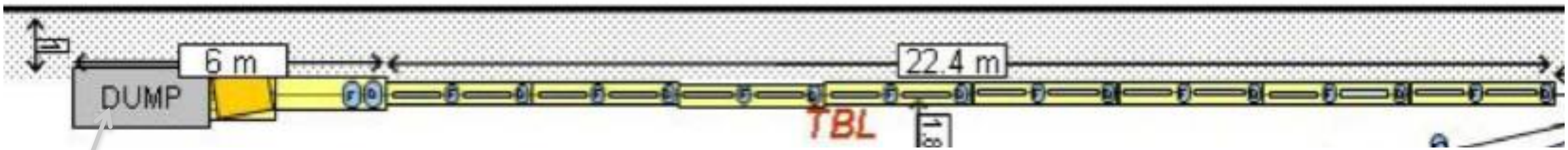




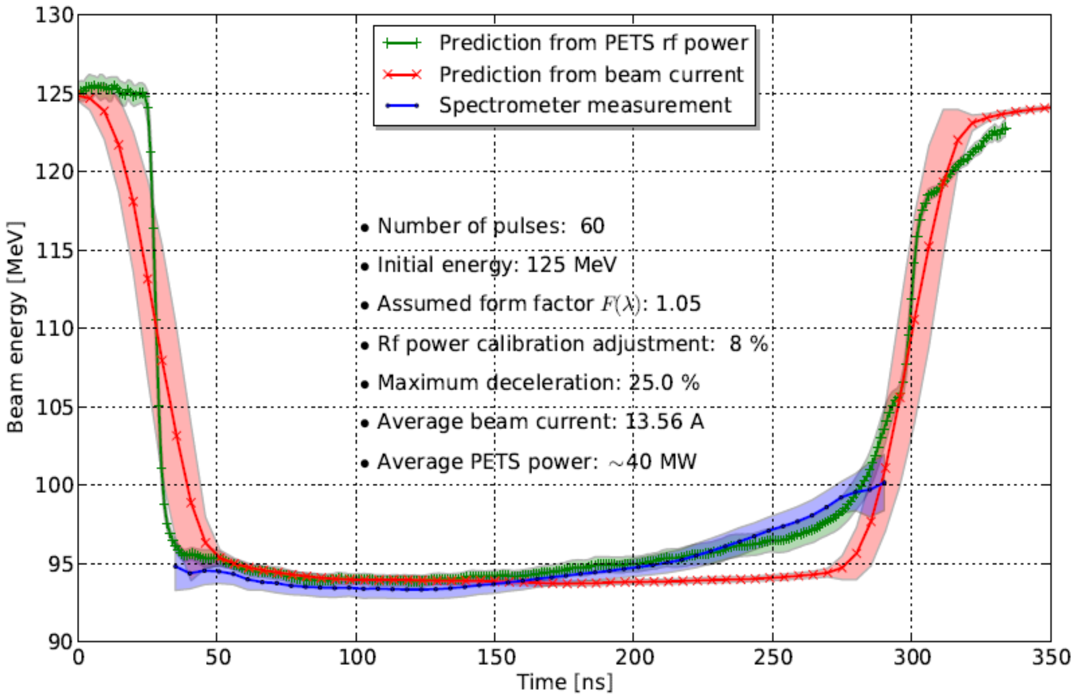
The drive beam is decelerated to 10% energy. The high energy transient must be equally well transported to the end of each 1 km decelerator.

Decelerator Test Beam Line

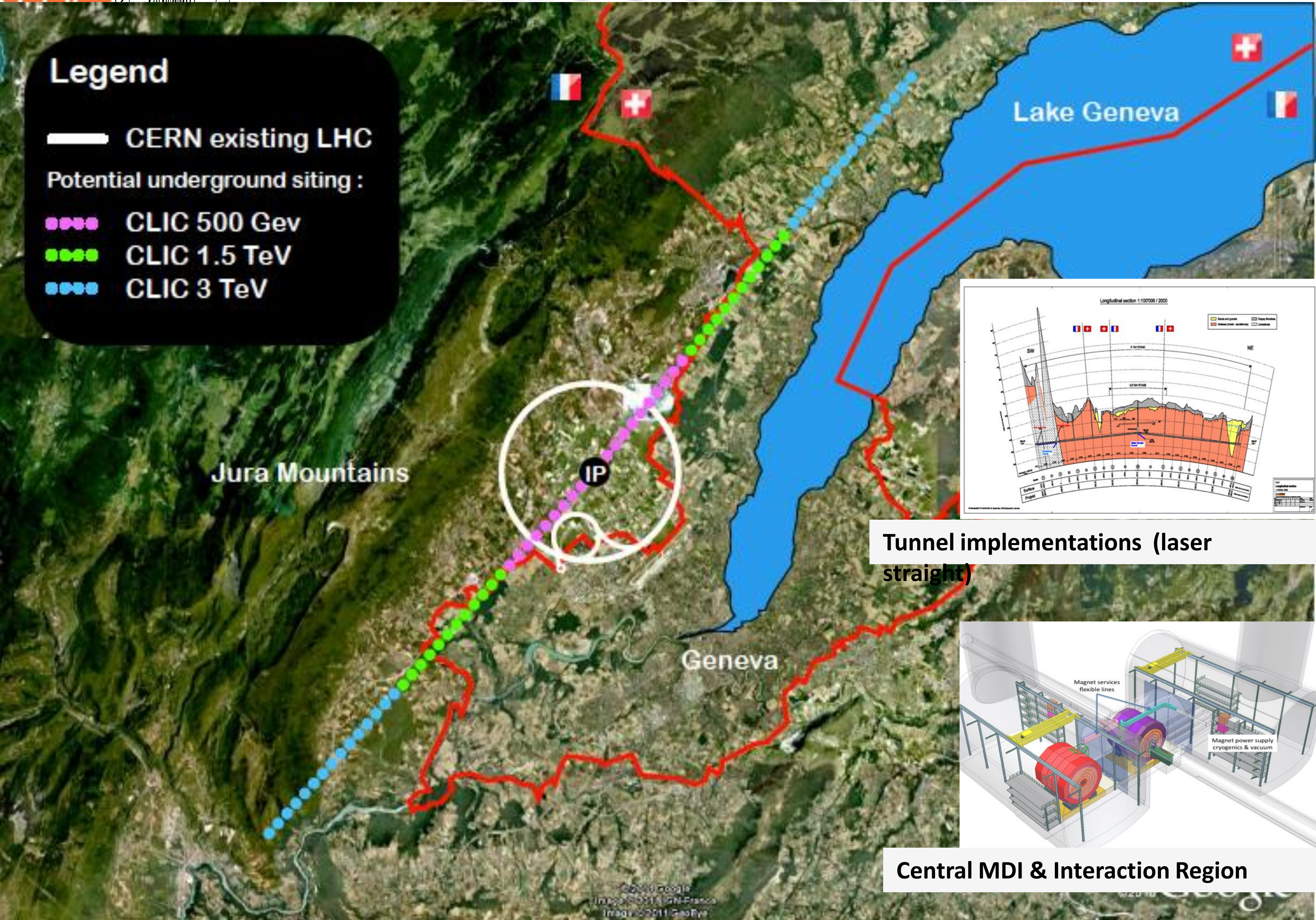
Test Beam Line: Transport of the 28A, 150 MeV CTF3 Drive Beam, while extracting more than 50% of the energy using 16 PETS, each producing CLIC level rf power, with small loss level.



Current status: 13 out of max. 16 PETS installed demonstarting > 35% drive beam deceleration. Correleation beam parameter versus rf power production and deceleration carefully studied and shows very good agreement.



CLIC site near CERN



Tunnel implementations (laser straight)

Central MDI & Interaction Region

Acknowledgements

- In addition to CLIC CDR and ILC TDR material, I have borrowed slides from linear collider experts: Frank Tecker, Barry Barish, Nick Walker, Alex Chao and many others

- I enjoyed useful discussions with Marc Ross, Jean-Pierre Delahaye and Steinar Stapnes while preparing this talk

Extra

Why a linear collider

General considerations

CLIC

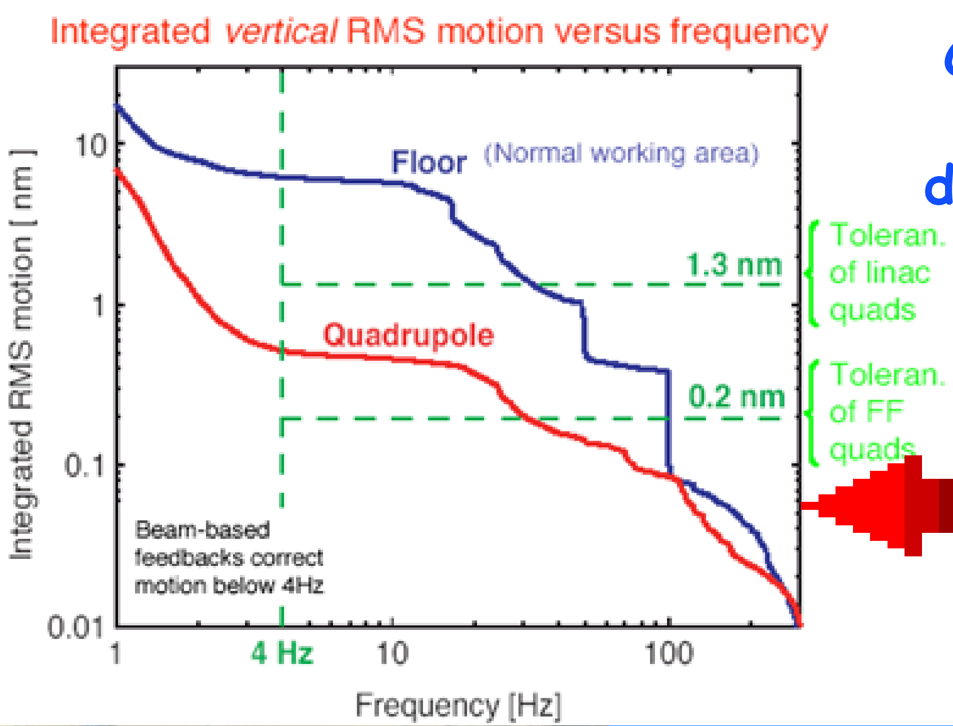
ILC

Summary

LC 500 GeV Main parameters

Centre-of-mass energy	NLC 500 GeV	ILC 500 GeV	CLIC 500 G Relaxed	CLIC 500 G Nominal
Total (Peak 1%) luminosity	$2.0(1.3)\cdot10^{34}$	$2.0(1.5)\cdot10^{34}$	$0.9(0.6)\cdot10^{34}$	$2.3(1.4)\cdot10^{34}$
Repetition rate (Hz)	120	5	50	
Loaded accel. gradient MV/m	50	33.5	80	
Main linac RF frequency GHz	11.4	1.3 (SC)	12	
Bunch charge 10^9	7.5	20	6.8	
Bunch separation ns	1.4	176	0.5	
Beam pulse duration (ns)	400	1000	177	
Beam power/linac (MWatts)	6.9	10.2	4.9	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)	3.6/40	10/40	7.5 / 40	4.8 / 25
Hor/Vert FF focusing (mm)	8/0.11	20/0.4	4/0.4	4/0.1
Bunch length (microns)	100	300	100	72
Hor./vert. IP beam size (nm)	243/3	640/5.7	248 / 5.7	202/ 2.3
Soft Hadronic event at IP	0.10	0.12	0.07	0.19
Coherent pairs/crossing at IP	10?	10?	10	100
BDS length (km)	3.5 (1 TeV)	2.23 (1 TeV)	1.87	
Total site length (km)	18	31	13.0	
Wall plug to beam transfer eff.	7.1%	9.4%	4.1%	
Total power consumption MW	195	216	240	

Nanometer Stabilisation



CLIC small quadrupole stabilized to nanometer level by active damping of natural floor vibration

RMS vibrations above 4 Hz

	Quad [nm]	Ground [nm]
Vertical	**0.43**	**6.20**
Horizontal	**0.79**	**3.04**
Longitud.	4.29	4.32

Vibration test stand

Prototype accelerating structure test areas


NLCTA at SLAC


Nextef at KEK


New klystron at CERN


ASTA at SLAC


Two-beam test stand at CERN

CLIC critical parameters

				Nominal	State of the art		Ratio
System	Item	Feasibility Issue	Unit	Value	Value	Where	Nominal/Art
Two Beam Acceleration	Drive beam generation	Fully loaded accel effic	%	97	-	-	-
		Freq&Current multipl	-	2*3*4	-	-	-
		Combined beam current (12 GHz)	A	4.5*24=100	-	-	-
		Combined pulse length (12 GHz)	ns	240	-	-	-
		Intensity stability	1.E-03	0.75	-	-	-
		Drive beam linac RF phase stability	Deg (1GHZ)	0.05	-	-	-
	Beam Driven RF power generation	PETS RF Power	MW	136	-	-	-
		PETS Pulse length	ns	176.5	-	-	-
		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)	Accelerating field (loaded)	MV/m	100	50	NLC	2
		Flat Top RF Pulse duration	ns	176.5	400		0.45
		RF Breakdown rate	/m	< 3·10-7	6.10-7		0.5
		Rf to beam transfer efficiency	%	28.5	33		0.9
	Two Beam Acceleration	Power producton and probe beam acceleration in Two beam module	MV/m - ns	100 - 170	-	-	-
					-	-	-
		Drive to main beam timing stability	psec	0.05	-	-	-
		Main to main beam timing stability	psec	0.07	-	-	-
Ultra low beam emittance & sizes	Ultra low Emittances	Norm. Emitttance generation	H/V (nm)	500/5	8800/100 25000/10	CesrTA SLS	18/2
		Emittance preservation: Blow-up	H/V (nm)	160/15	15000/5800	SLC	94/390
	Nanometer beam sizes	Strong focusing: β*eff /L* from IP	mm/m	0.1/3.5	0.1/0.4	FFTB/SLAC	1/8
		Nanometer beam sizes at IP	H/V (nm)	40/1	70		70
	Alignment	Main Linac components	µm	10	100	?	10
		Final-Doublet tolerance	µm	10			
	Vertical stabilisation	Quad Main Linac	nm>1 Hz	1.5	2nm>2Hz	STACIS/ SLAC	10
		Final Doublet (with feedbacks)	nm>4 Hz	0.2			
Operation and Machine Protection System (MPS)		72MW@2.4GeV			1.4 MW@1GeV	SNS	50
		14MW@1.5TeV					10

CLIC Feasibility status

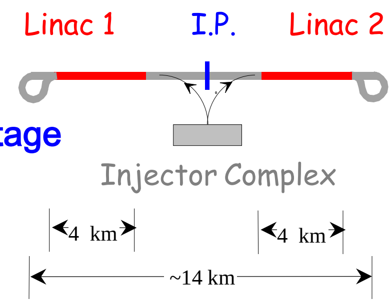
System	Item	Feasibility Issue	Unit	Nominal	Achieved	How	Feasibility
Two Beam Acceleration	Drive beam generation	Fully loaded accel effic	%	97	95	CTF3	✓
		Freq&Current multipl	-	2*3*4	2*4	CTF3	✓
		12 GHz beam current	A	4.5*24=100	3.5*8=28	CTF3	✓
		12 GHz pulse length	nsec	240	240	CTF3	✓
		Intensity stability	1.E-03	0.75	0.6	CTF3	✓
		Drive beam linac RF phase stability	Deg (1GHZ)	0.05	0.035	CTF3, XFEL	✓
	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	✓
		PETS ON/OFF	-	@ 50Hz	-	CTF3/TBTS	2011
		Drive beam to RF efficiency	%	90%	-	CTF3/TBL	2010-11
		RF pulse shape control	%	< 0.1%	-	CTF3/TBTS	
	Accelerating Structures (CAS)	Structure Acc field	MV/m	100	100	CTF3 Test Stand, SLAC, KEK	✓
		Structure Flat Top Pulse length	ns	170	170		✓
		Structure Breakdown rate	/m MV/m.ns	< 3·10-7	5·10-5(D)		2010-11
		Rf to beam transfer efficiency	%	27	15		2010-11
	Two Beam Acceleration	Power producton and probe beam acceleration in Two beam module	MV/m - ns	100 - 170	55 - 170	TBTS	2011-12
		Drive to main beam timing stability	psec	0.05	-	CTF3	2012
		Main to main beam timing stability	psec	0.07	-	CTF3	2012
Ultra low beam emittance & sizes	Ultra low Emittances	Emitttance generation H/V	nm	500/5	3000/12	ATF, NSLS/SLS + simulation	✓
		Emittance preservation: Blow-up	nm	160/15	160/15		2010-12
	Alignment	Main Linac components	microns	15	10 (princ.)	Alignement & Mod.Test Bench	2010
		Final-Doublet	microns	2 to 8			2010
	Vertical stabilisation	Quad Main Linac	nm>1 Hz	1.5	0.13 (principle)	Stabilisation Test Bench	2010-12
		Final Doublet (assuming feedbacks)	nm>4 Hz	0.2			

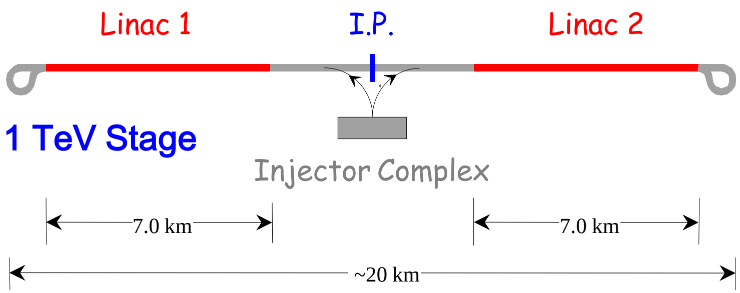
CLIC energy stages

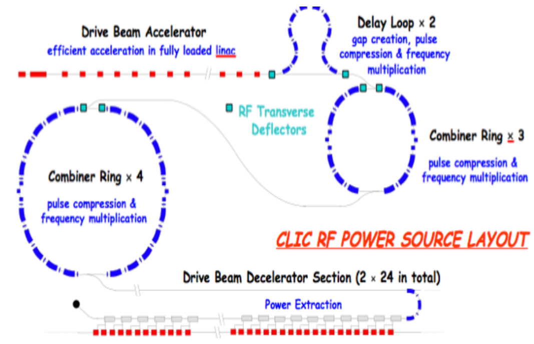
CLIC two-beam scheme : energy staging is straight-forward.

Lower energy machines can run most of the time during the construction of the next stage.

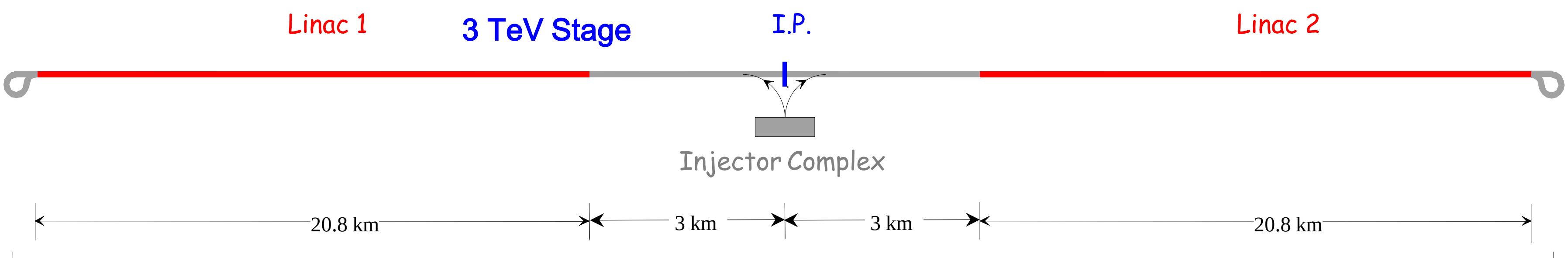
Physics results will determine the energies of the stages.







The drive beam complex will stay the same for all stages.

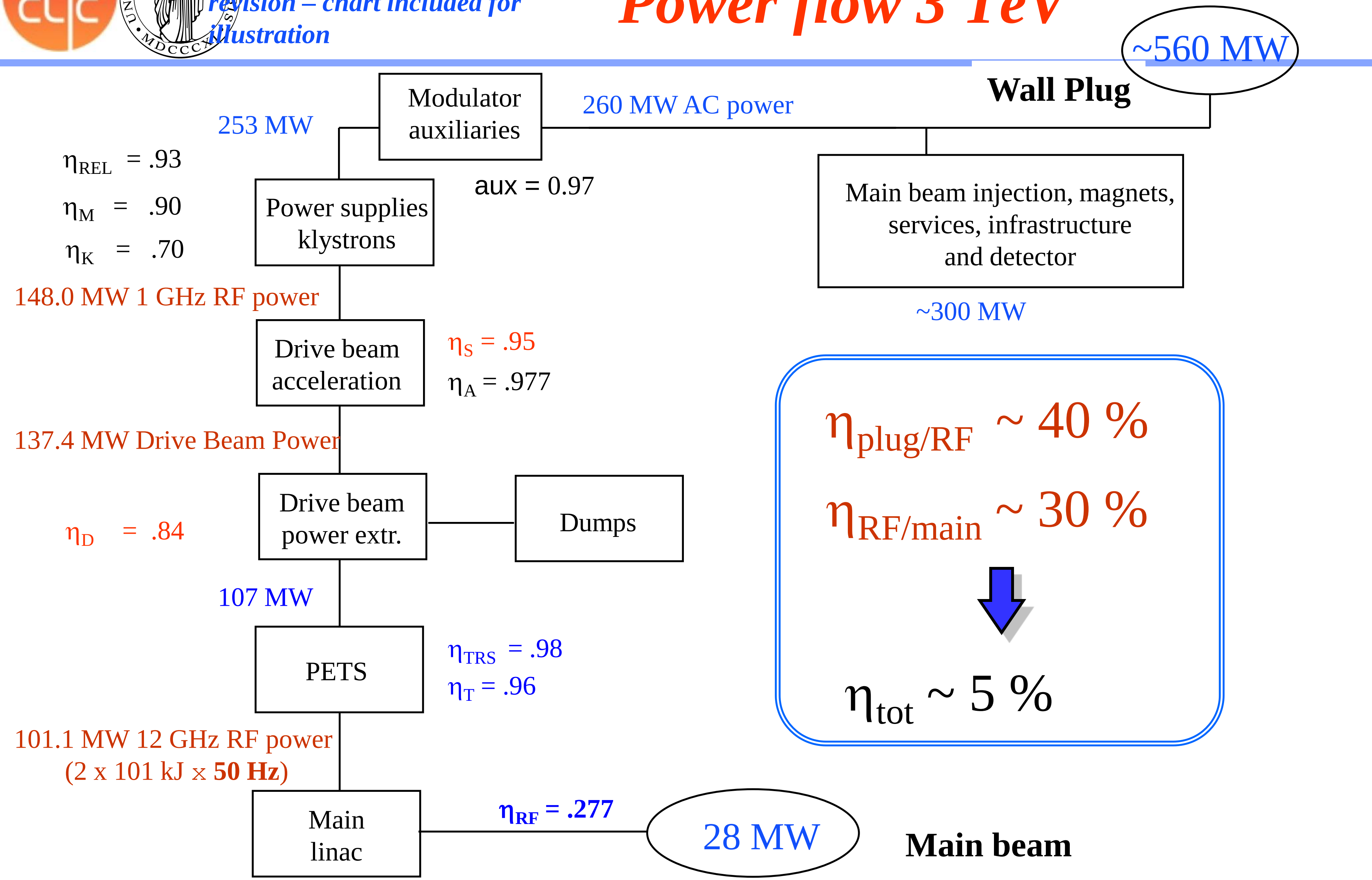


CLIC main parameters

Centre-of-mass energy	500 GeV	3 TeV
Total (Peak 1%) luminosity	$2.3(1.4)\cdot10^{34}$	$5.9(2.0)\cdot10^{34}$
Total site length (km)	13.0	48.3
Loaded accel. gradient (MV/m)	80	100
Main linac RF frequency (GHz)	12	
Beam power/beam (MW)	4.9	14
Bunch charge (10^9 e+/-)	6.8	3.72
Bunch separation (ns)	0.5	
Beam pulse duration (ns)	177	156
Repetition rate (Hz)	50	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)	4.8/25	0.66/20
Hor./vert. IP beam size (nm)	202 / 2.3	40 / 1
Hadronic events/crossing at IP	0.19	2.7
Coherent pairs at IP	100	$3.8\ 10^8$
Wall plug to beam transfer eff	4.1%	5.0%
Total power consumption (MW)	240	560

Exact numbers are under revision – chart included for illustration

Power flow 3 TeV



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 preservation during generation, acceleration and focusing
  - Alignment and stabilisation
- Operation and Machine Protection System (MPS)
- Detector
  - Adaptation to short interval between bunches
  - Adaptation to large background at high beam collision energy

CLIC specific

CLIC ILC Common Issues
CLIC more challenging requirements

*** Feasibility issues planned to be addressed by end 2011 (CDR)**

*** Consolidated performance, power and cost issues adressed by 2016 (planned date for PIP)**

CLIC physics up to 3 TeV

LHC will indicate what physics, and at which energy scale

Potential Physics in 0.5-3 TeV range?

Higgs physics:

- Complete study of the light standard-model Higgs boson, including rare decay modes (rates factor ~5 higher at 3 TeV than at 500 GeV)
  - Higgs coupling to leptons (universality)
  - Study of triple Higgs coupling using double Higgs production
  - Higgs spin
- Study of heavy Higgs bosons

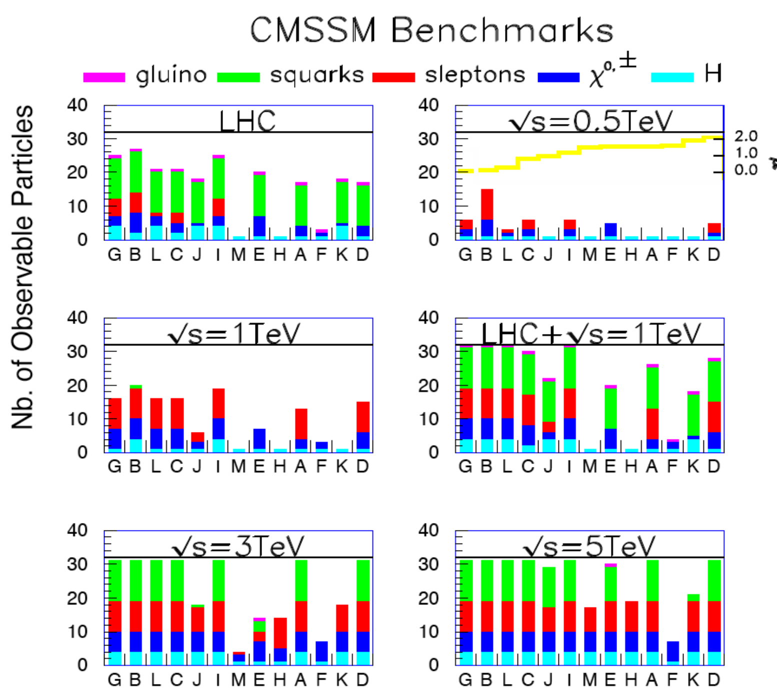
Supersymmetry:

- Extensive reach to measure SUSY particles

In addition:

- Probe for theories of extra dimensions
- New heavy gauge bosons (e.g. Z')
- Excited quarks or leptons

http://lcd.web.cern.ch/LCD

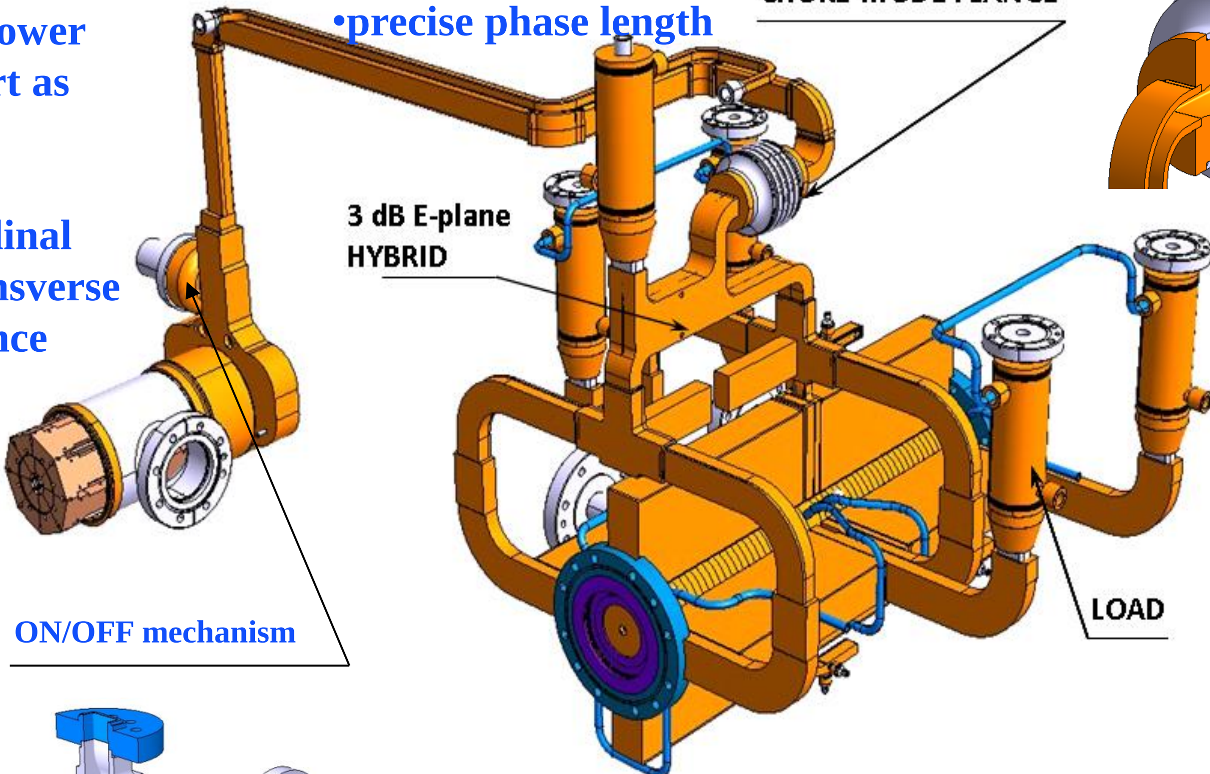


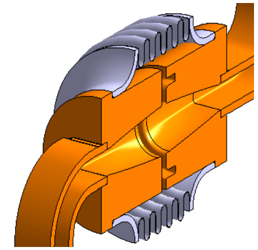
SUSY reach for an e+e- collider

CLIC two-beam acceleration rf network

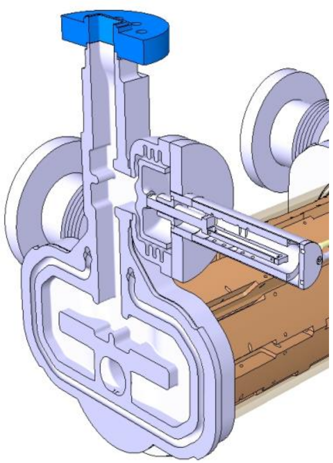
PETS
- high-power
- as short as possible
- low longitudinal and transverse impedance

Waveguide network
- high power
- precise phase length



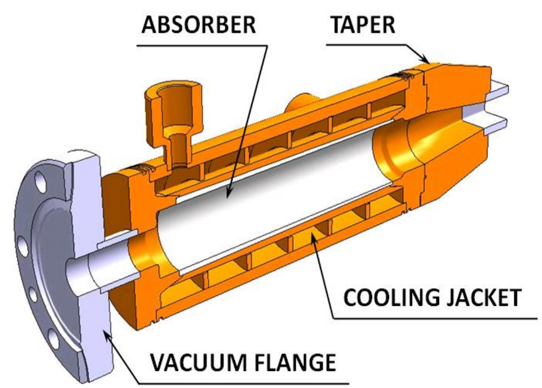


Choke mode flange
- independent alignment of main and drive beam

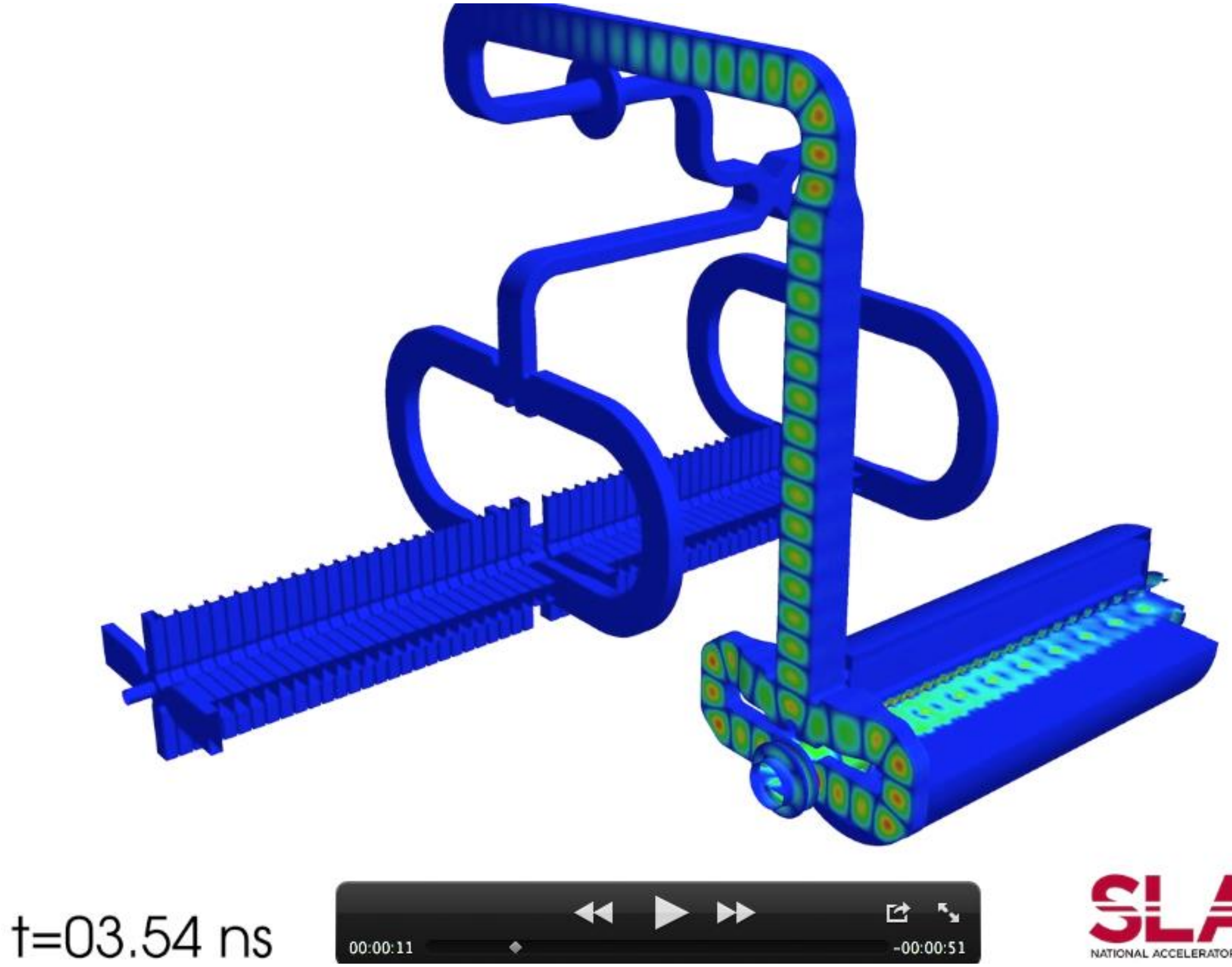


On/ramp/off
- necessary (?) to react to breakdown and/or failure

Accelerating structure
- high-gradient
- as long as possible
- micron precision
- transverse wakefield suppression



Simulation status: full 3D e.m. simulations



Full 3D FEM simulations of entire drive beam-rf power-main beam chain with SLAC/ACD ACE3P codes (Courtesy of A. Candel, SLAC). Allows for detailed studies of power production efficiency and potential HOM coupling drive beam to main beam.

DR technology and experimental program

- **Super-conducting wigglers**

  Demanding magnet technology combined with cryogenics and high heat load from synchrotron radiation (absorption)

- **High frequency RF system**

  1 GHz RF system respecting power and transient beam

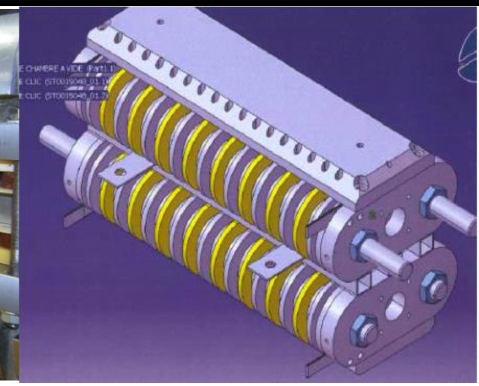
- **Coatings, chamber design and ultra-low vacuum**

- Electron cloud mitigation, low-impedance, fast-ion instability

- **Kicker technology**
  - Extracted beam stability

- **Diagnostics for low emittance**

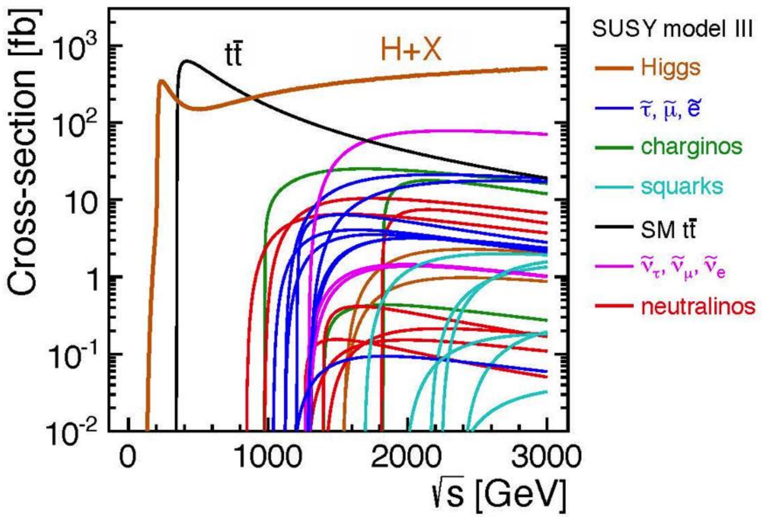
Parameters	BINP	CERN/Karlsruhe
B_{peak} [T]	2.5	2.8
λ_W [mm]	50	40
Beam aperture full gap [mm]	13	13
Conductor type	NbTi	$NbSn_3$
Operating temperature [K]	4.2	4.2



Experimental program set-up for measurements in storage rings and test facilities:

ALBA (Spain), ANKA (Germany), ATF (Japan), CESRTA (USA), Synchrotron (Australia), SOLEIL (France)..

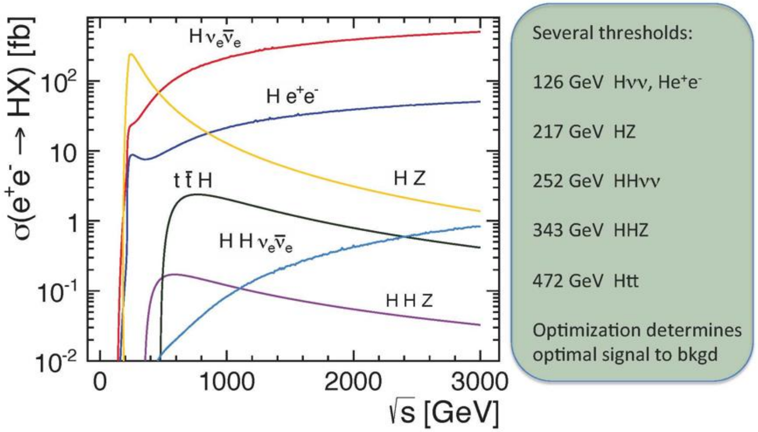
- **Physics case for the Linear Collider:**
  - **Higgs physics (SM and non-SM)**
  - **Top**
  - **SUSY**
  - **Higgs strong interactions**
  - **New Z' sector**
  - **Contact interactions**
  - **Extra dimensions**
  - **....**



Recently: Further work on completing picture of Higgs prospects at ~350 GeV, ~1.4 TeV, ~3 TeV, example for CLIC:

collision energy Polarization e⁻/e⁺	√s = 1.4 TeV unpolarized	√s = 1.4 TeV -80% / +30%	√s = 3.0 TeV unpolarized	√s = 3.0 TeV -80% / +30%
Δ σ(HHνν)	≈ 22%	≈ 18%	≈ 10%	≈ 7%
Δ λ_{HHH}	≈ 28%	≈ 22%	≈ 16%	≈ 11%
Numbers with polarized beams obtained by scaling signal and background cross sections, ignoring polarization-dependent changes to kinematic properties.				all cross section values: mH = 120 GeV

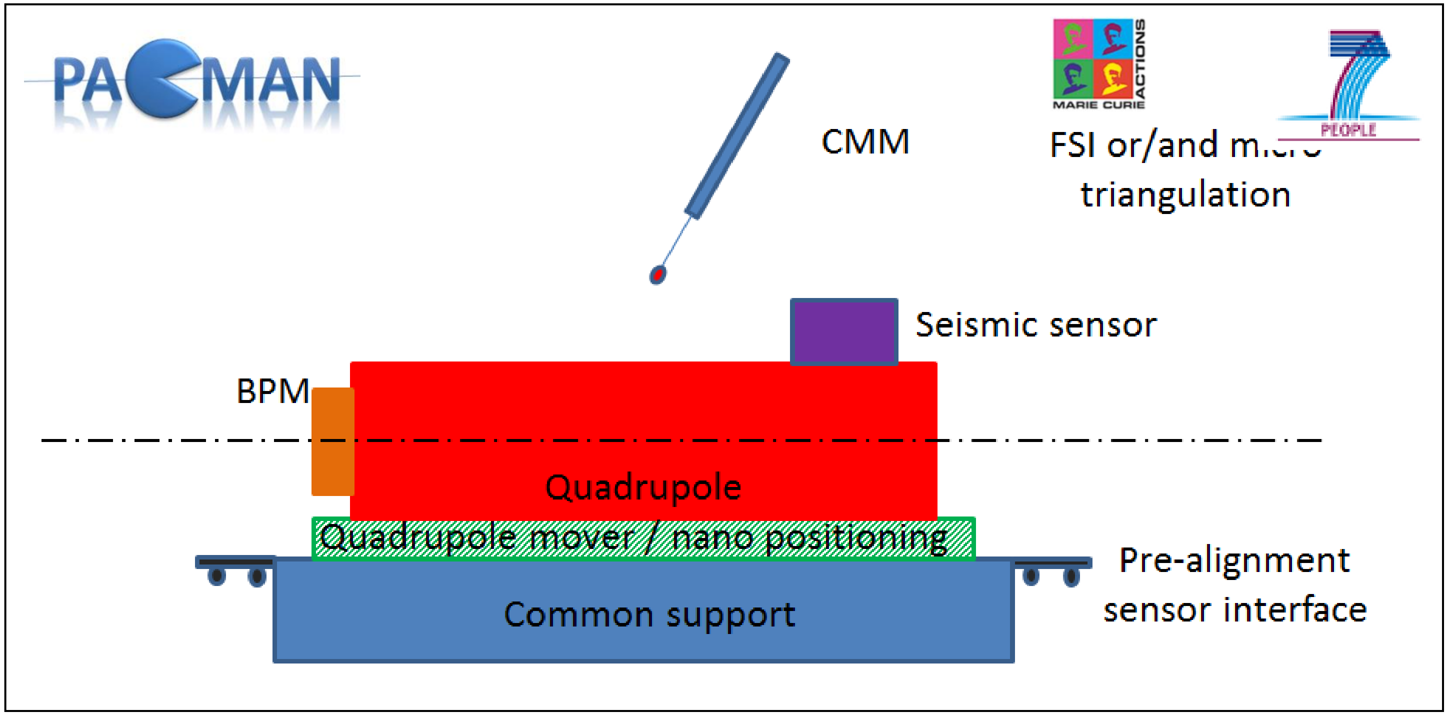
Higgs boson Production Cross-Sections



Lebrun et al., arXiv:1209.2543

"PACMAN" test-bench

Particle Accelerator Components Metrology and Alignment to the Nanometre scale



- Develop an alternative solution integrating all the alignment steps and technologies integrated at the same time and location (CMM machine)
- Build **a full prototype** at CERN
- 15 academic and industrial partners, EC funds **10 PhD students** (Marie Curie) : applications process just finished