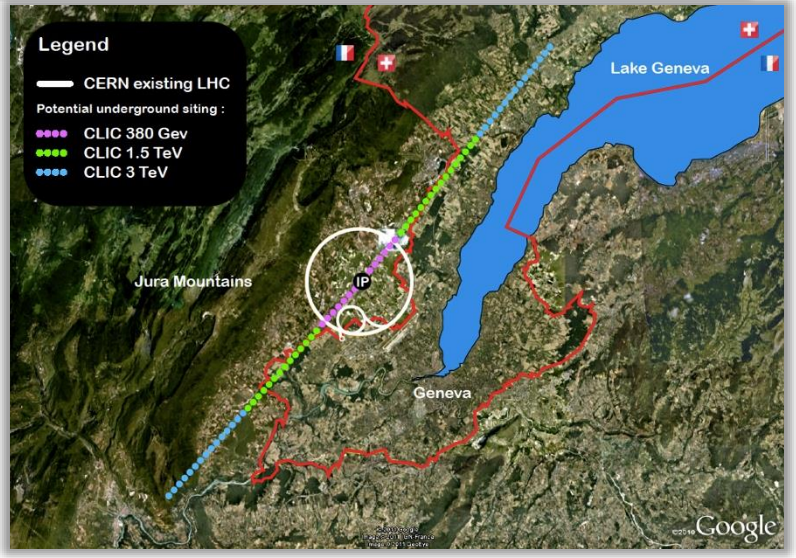
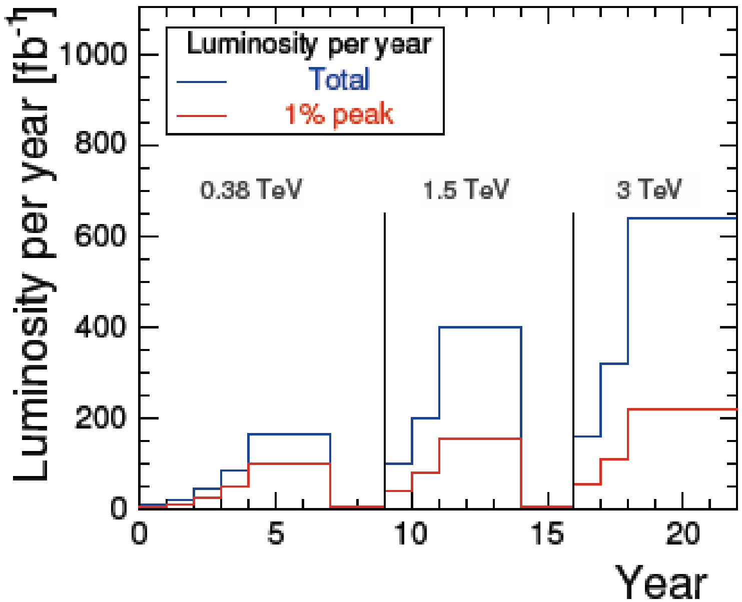
CLIC 380 GeV -> 3 TeV

Goal for next strategy update (end 2018): Present a CLIC project that is a "credible" option for CERN beyond LHC, a Project Implementation Plan.
Guidelines used internally:

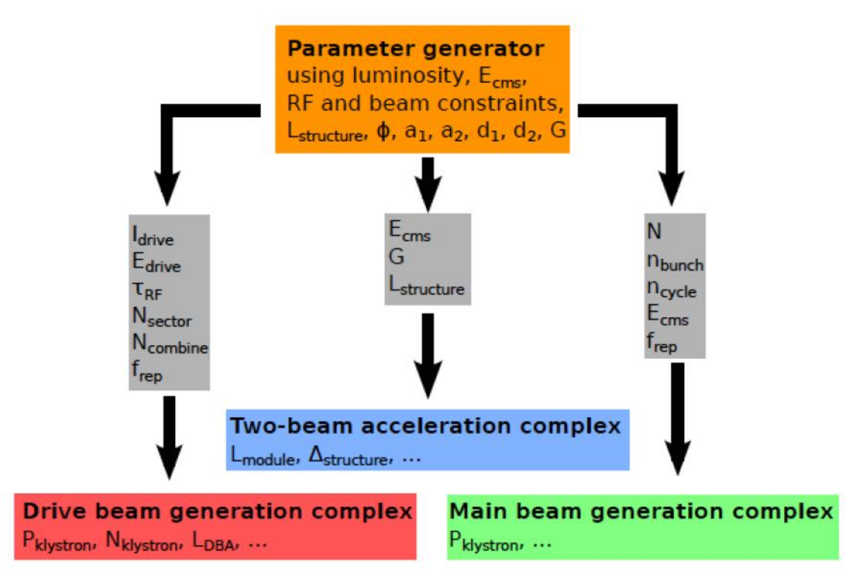
- Adapt to physics results – LHC mostly – taking into account LHC at 13-14 TeV as results become available (be flexible)
- Physics no later than 2035, solid luminosities from Higgs/top at 380 GeV to 3 TeV (staging)
- Initial costs compatible with current CERN budget level (order LHC+50%) (staging)
- Upgradable in 2-3 stages over a 20-30y period, without major (max 3-4 years) operational breaks, and with upgrade costs also in reasonable agreement with current budget level.
- Cover accelerator, detector, physics

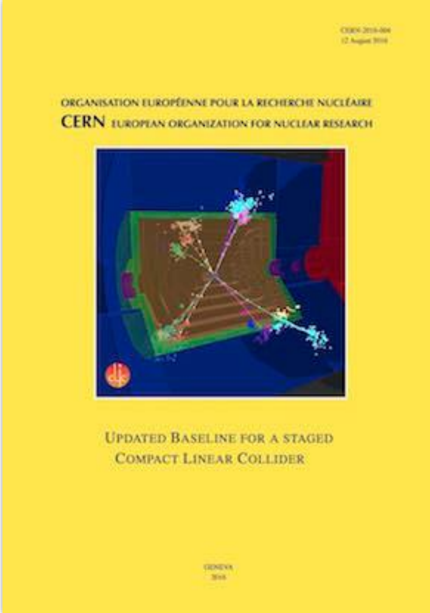
Parameter	Unit	380 GeV	3 TeV
Centre-of-mass energy	TeV	0.38	3
Total luminosity	$10^{34}cm^{-2}s^{-1}$	1.5	5.9
Luminosity above 99% of √s	$10^{34}cm^{-2}s^{-1}$	0.9	2.0
Repetition frequency	Hz	50	50
Number of bunches per train		352	312
Bunch separation	ns	0.5	0.5
Acceleration gradient	MV/m	72	100
Site length	km	11	50





CLIC cost and power optimisation

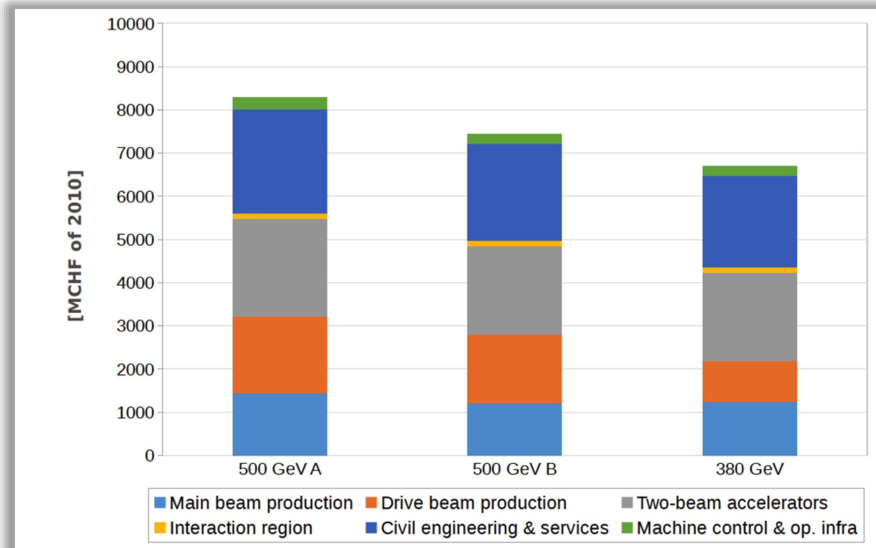




Yellow report: New reference plots for power, costs, luminosities, physics, etc

- CDR 2012: Cost and power estimated (bottom up, WBS based, reviewed)

- 2016: Cost and power update for 380 GeV drivebeam based machine made
- Still a very limited exercise:
  - Optimize accelerator structures, beam-parameters and RF system -> defines machine layout for 380 GeV
  - Remove pre-damping ring for electrons, scale DB better
  - Largely scaling from 500 GeV



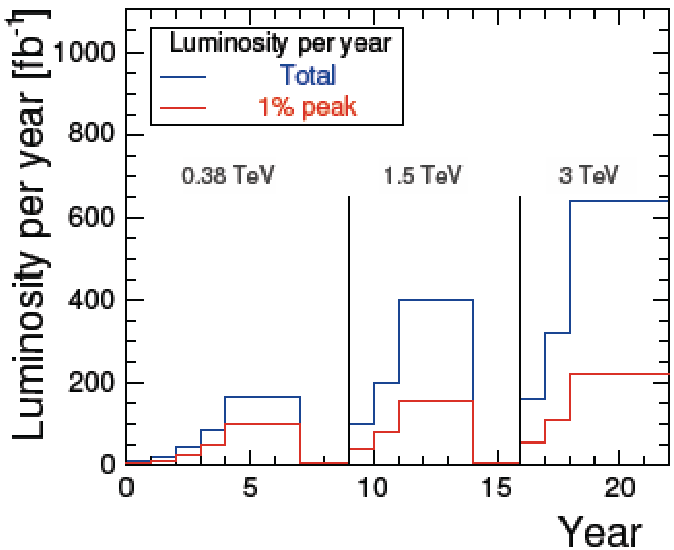
Cost – versus E and L

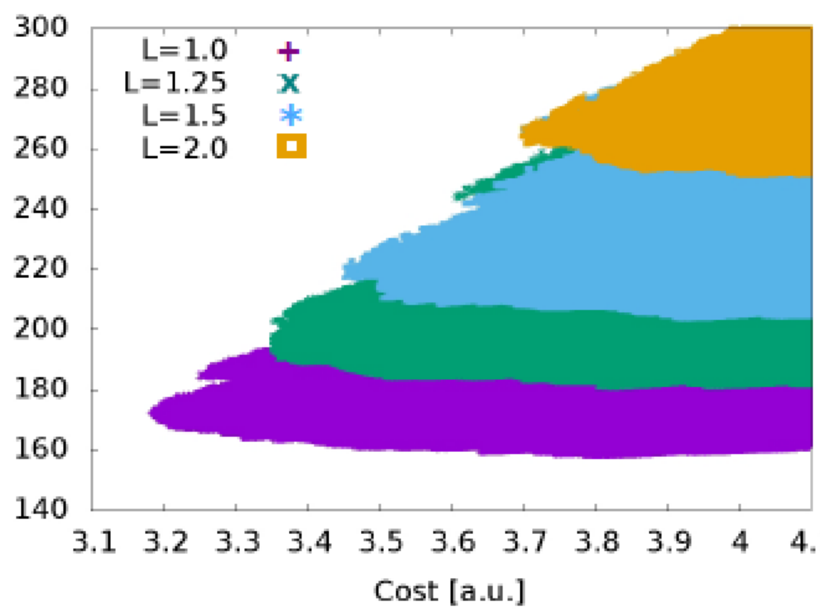
Table 11: Value estimate of CLIC at 380 GeV centre-of-mass energy.

	Value [MCHF of December 2010]
Main beam production	1245
Drive beam production	974
Two-beam accelerators	2038
Interaction region	132
Civil engineering & services	2112
Accelerator control & operational infrastructure	216
Total	6690

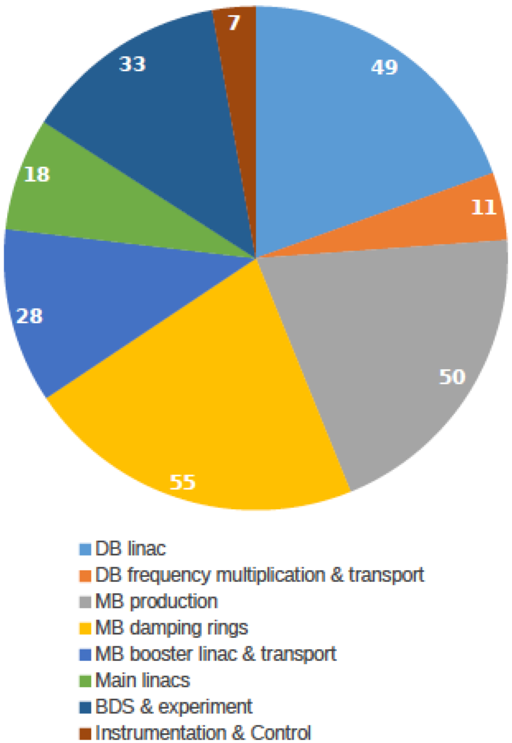
Electron pre-damping ring can be removed with good electron injector (is removed in these estimates).

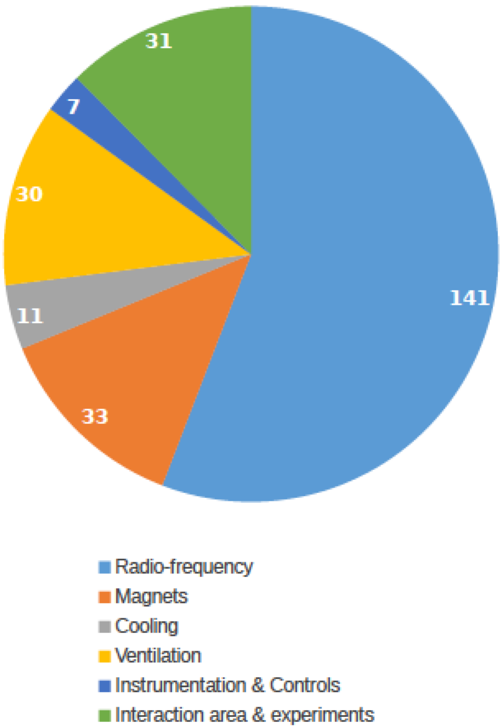
- Further design optimization possible but will/could influence luminosity
- Is increasing the time it takes to reach 500 fb-1 by 2 years a good tradeoff versus 0.5 BCHF saving ?

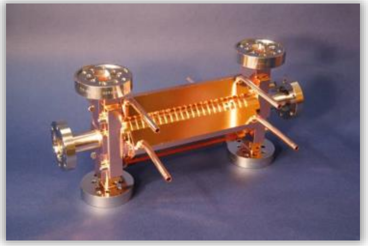




Power and energy



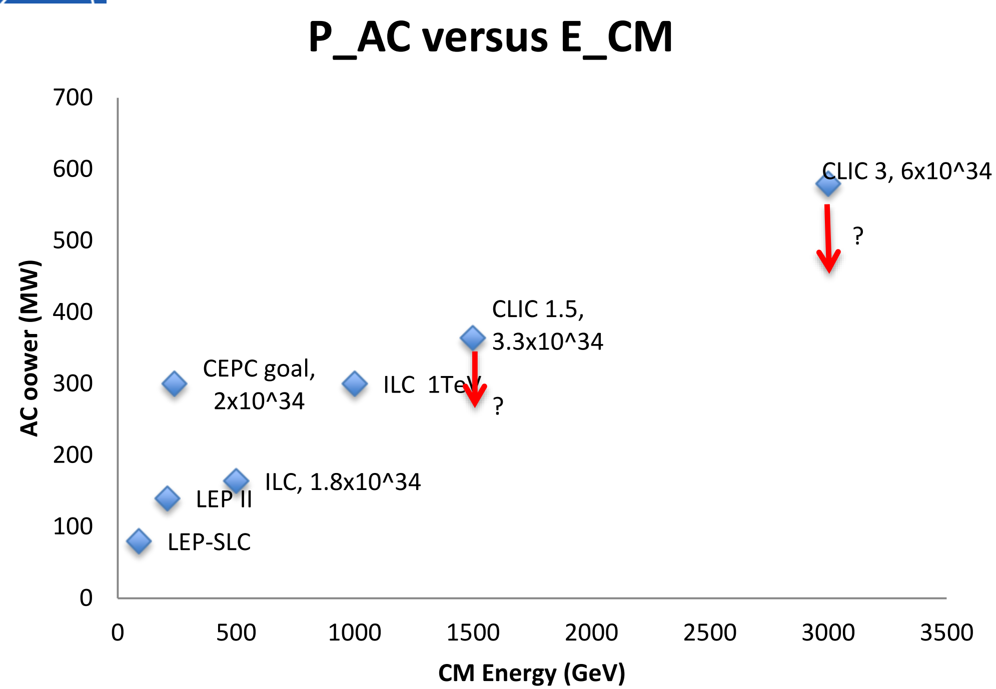




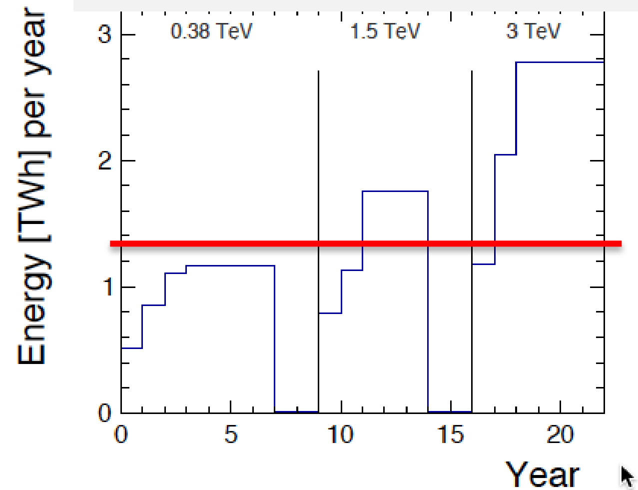
Power/energy reductions are being looked at – assuming structures optimised, however large contributions from:

- Klystrons – increase efficiency
- Magnets
- Ventilation/cooling optimisation

Power and energy



CERN energy consumption 2012: 1.35 TWh



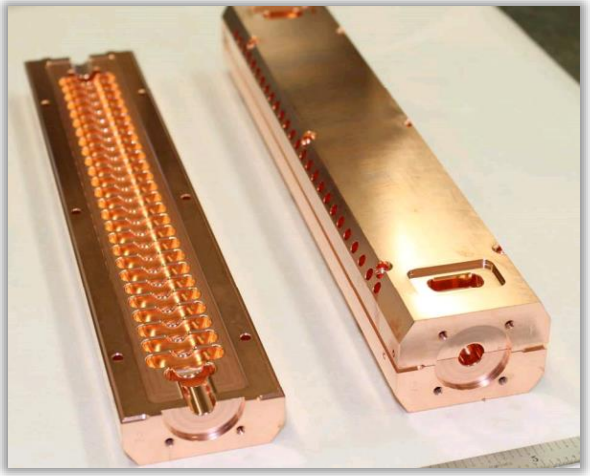
Power/energy reductions by operational choices:

- Look at daily and yearly fluctuation – can one run in "low general demand" periods
- Understand and minimize the energy (consider also standby, MD, down periods, running
- Consider where the power is dissipated (distributed or central), recoverable ?

Cost optimisation

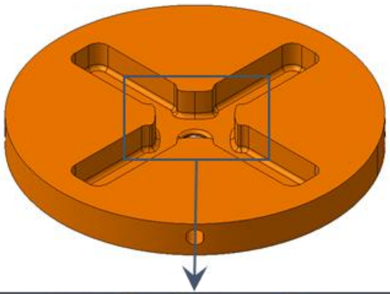
Beyond the parameter optimization there are other on-going developments (design/technical developments):

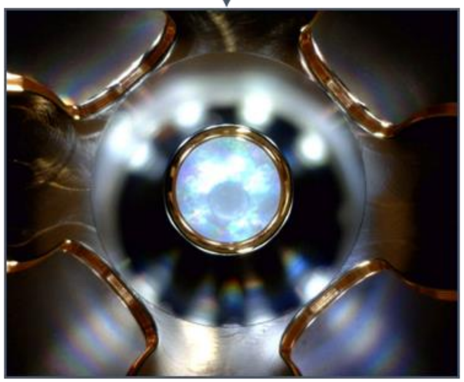
- Optimize drive beam accelerator klystron system (Syratchev) – also for power (next slides)
- Dimension drive beam accelerator building and infrastructure are for 3 TeV, dimension to 1.5 TeV results in large saving
- Systematic optimization of injector complex linacs in preparation – also for power
- Module optimisation studies
- Different structure production



Assembly – towards industrialization

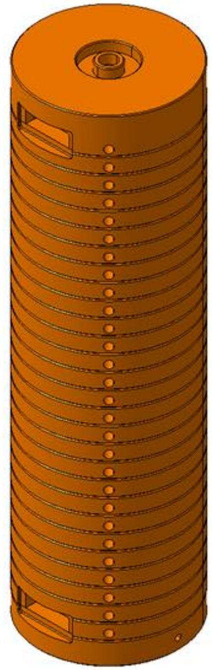
AS DISC





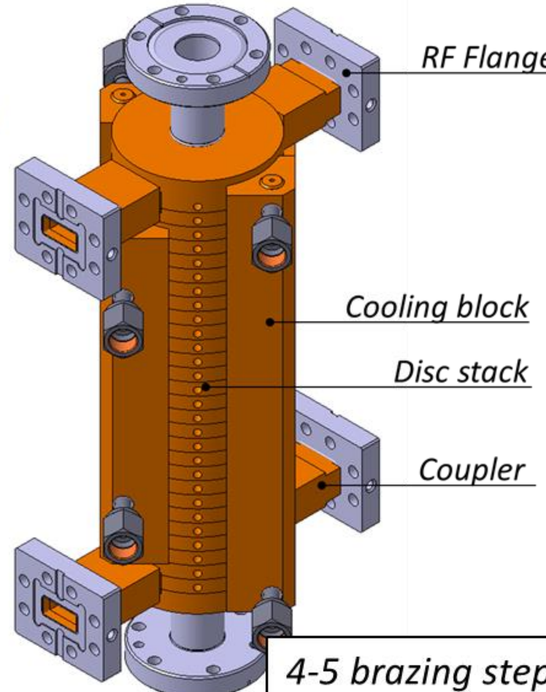
Acceptance at CERN

AS DISC STACK BONDING



Acceptance at CERN

AS ASSEMBLY



4-5 brazing steps

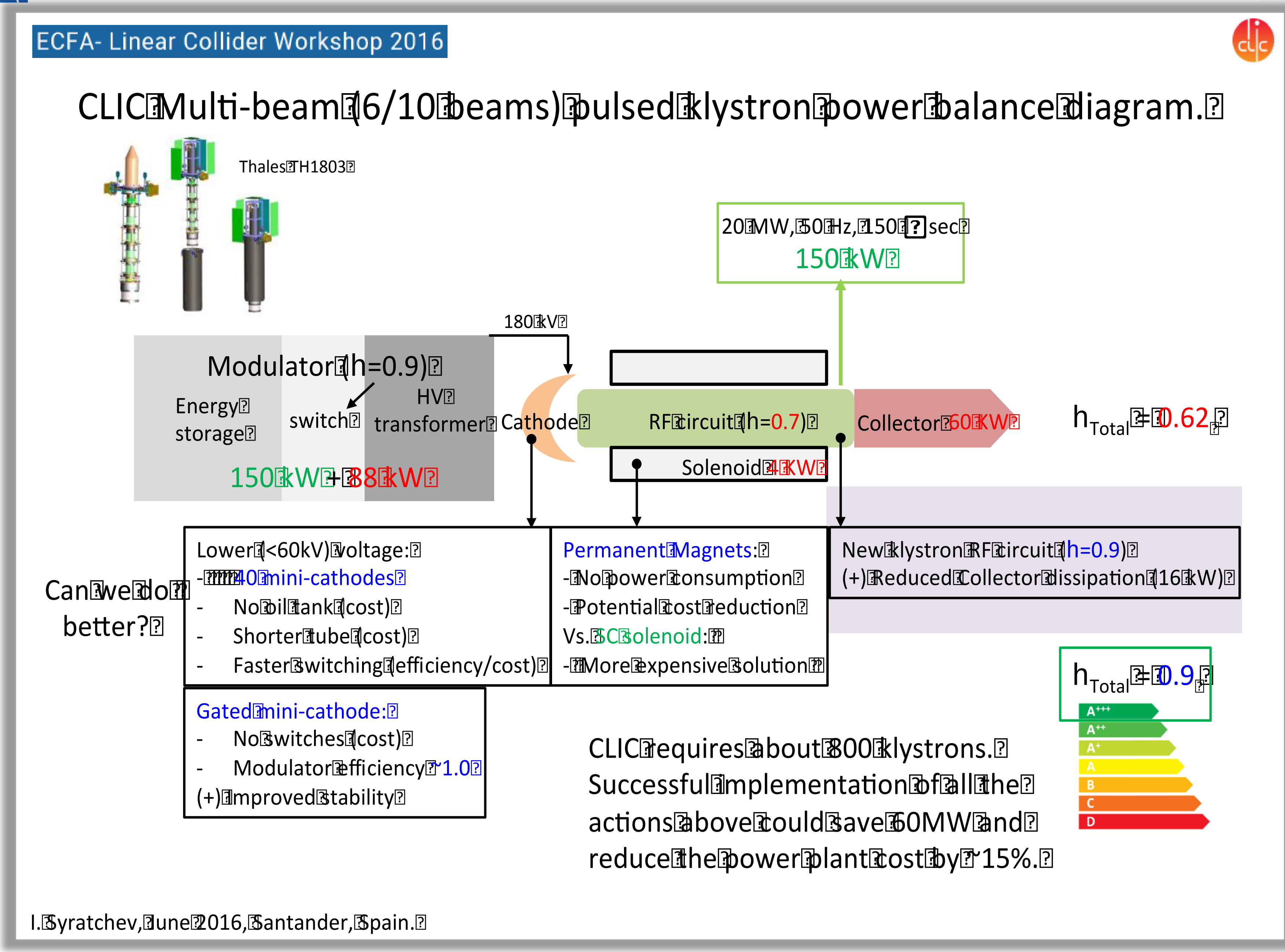
Cell shape accuracy - 0.004 mm
Flatness - 0.001 mm
Surface roughness - Ra 0.025 µm

Commercial suppliers:
- 4 qualified companies for UP machining;
- Single-crystal diamond tool required.

REQUIREMENTS:
- Alignment
- Special tooling
- Clean environment

Suppliers:
- 3 qualified companies for brazing/bonding operations, supervision by CERN;
- Collaborators.

Klystron/modulator efficiencies

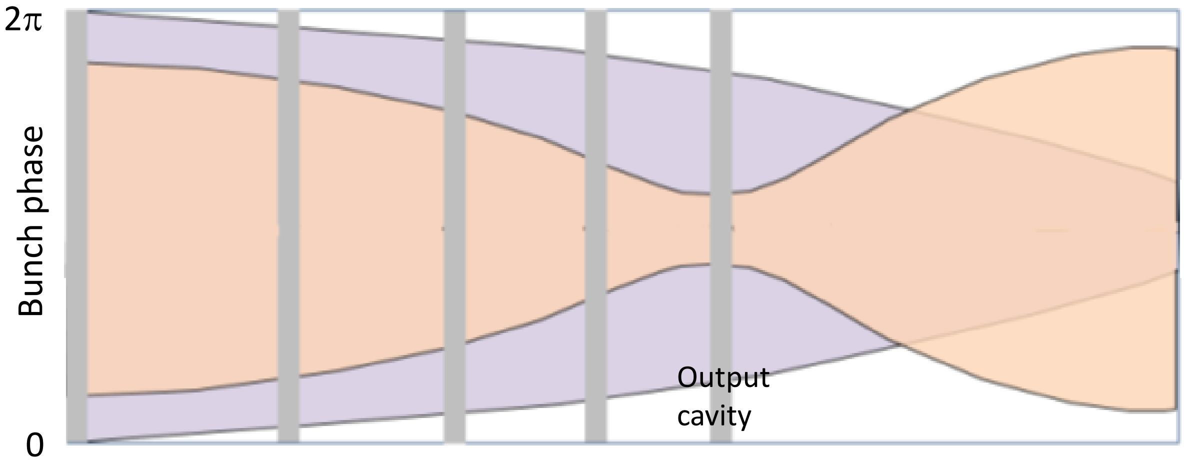


The new bunching technology shows a potential to boost klystron efficiency to the 90% level.

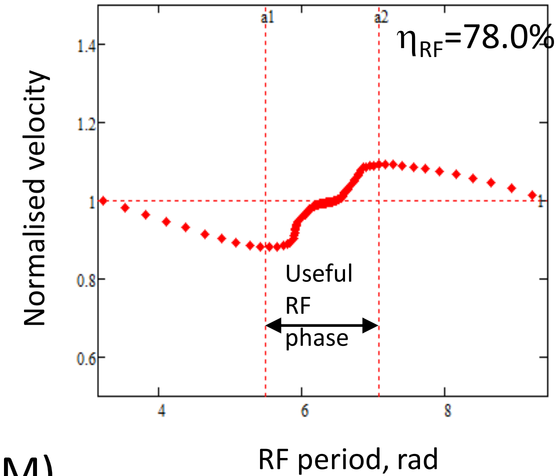
Link: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7194781

CLIC MBK preliminary optimisation

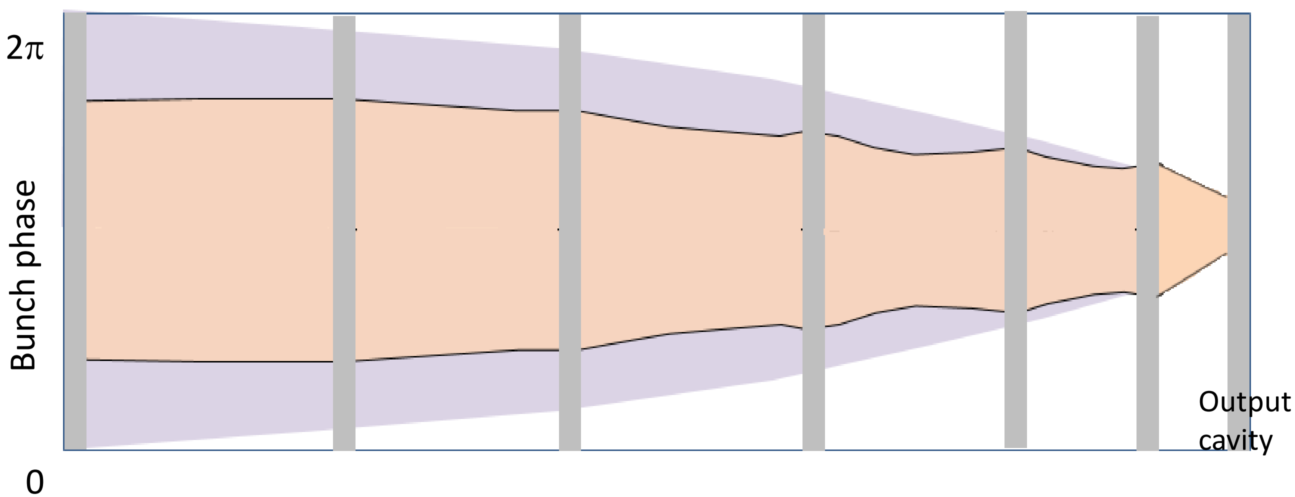
"Classical" bunching

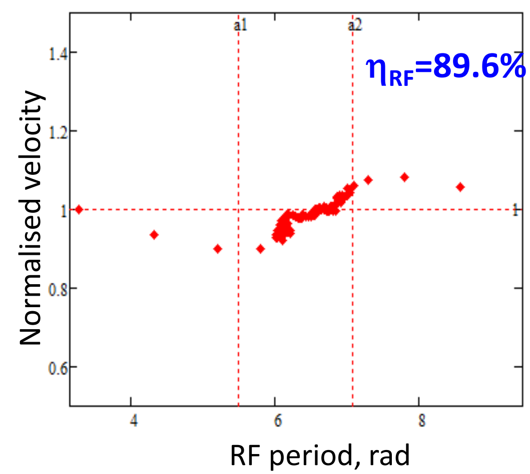


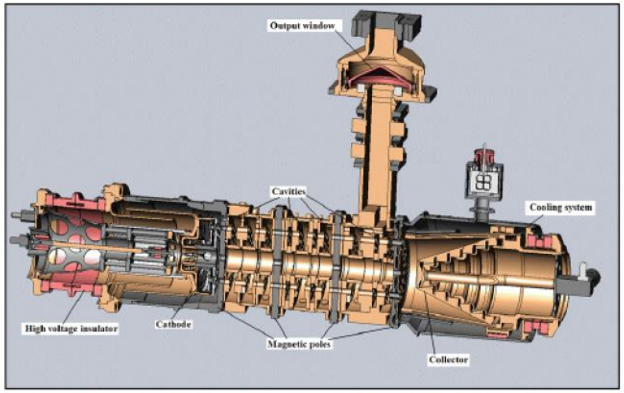
Electrons velocities distributions prior entering the output cavity

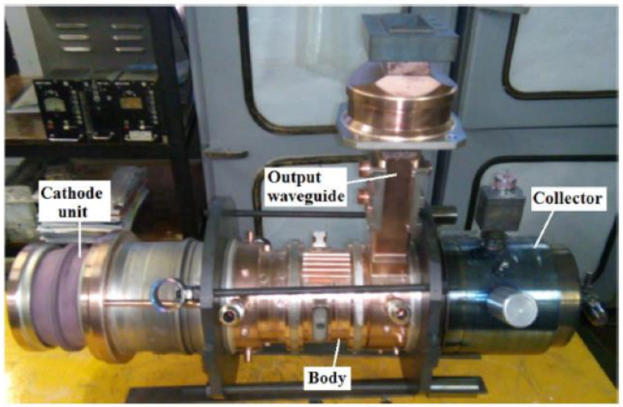


New bunching with core oscillations (COM)



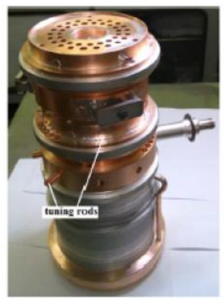


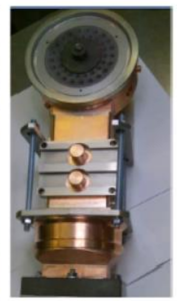


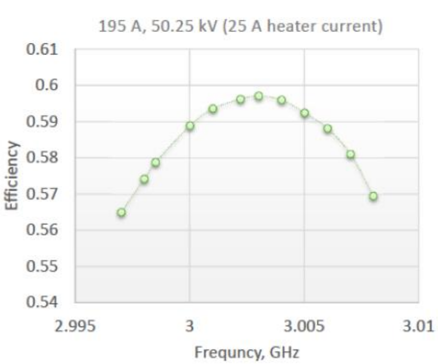


The first commercial S-band MB tube prototype which employs the new bunching technology (BAC). Contractual technical specification:

- 40 beams
- Permanent Magnets focusing system
- Voltage: <60 kV
- Peak power: >6.0 MW
- Efficiency: >60%
- Pulse length: 5 microsecond
- Repetition rate: 300 Hz
- Average power: 30 kW







The best klystron performance was measured at 3.003 GHz:

- Efficiency: 59.7%
- Total current: 195 A
- Voltage: 50.25 kV
- μK/beam =0.432
- Beam power: 9.8 MW
- RF power: 5.84 MW
- Power gain: 46.7 dB

The first commercial prototype of high efficiency BAC MBK tube was successfully tested at CERN. The results are very encouraging and prove that new bunching technology can significantly boost the efficiency of klystron amplifiers. In this particular case the klystron efficiency was increased from 42% to almost 60% simply by replacing the original RF circuit with new BAC RF circuit. Not to forget about the importance of operation at low voltage and cost/weight savings due to PPM focusing.

Where else these design approach could be interesting for CLIC ?

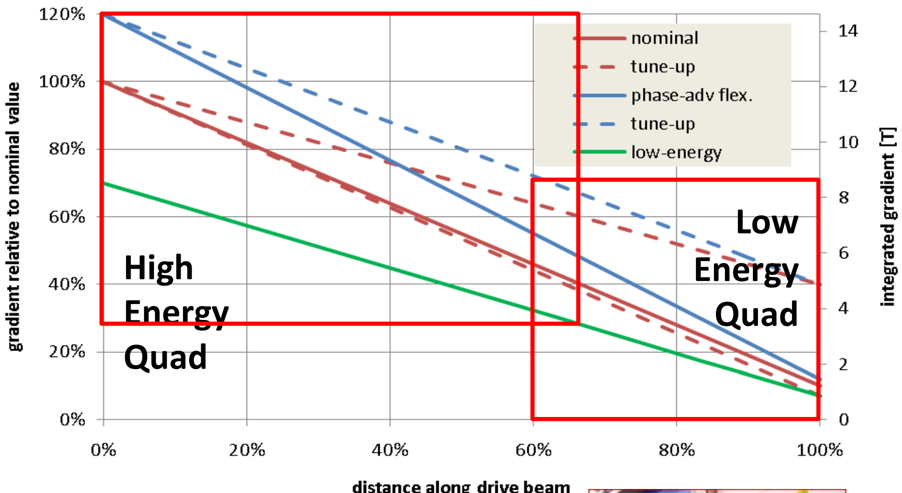
DRIVE BEAM

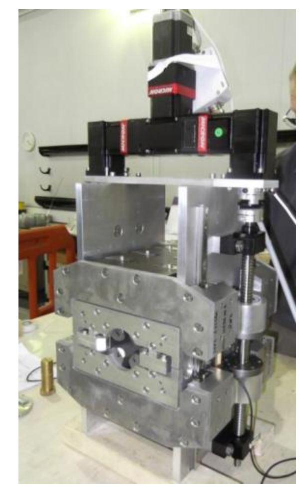
Type	Magnet type	Total	Effective Length [m]	H	V	Strength	Units	Min field	Max field	Rel Field Accuracy	Higher Harmonics [Tm]	per magnet [kW]	total [MW]
DBQ	Quadrupole	41400	0.194	26	26	62.78T/m		10%	120%	1E-03	1.0E-04	0.5	17.0
MBTA	Dipole	576	1.5	40	40	1.6T		10%	100%	1E-03	1.0E-04	21.6	12.4
MBCOTA	Dipole	1872	0.2	40	40	0.07T		-100%	100%	1E-03	1.0E-03	0.3	0.5
QTA	Quadrupole	1872	0.5	40	40	14T/m		10%	100%	1E-03	1.0E-04	2.0	3.7
SXTA	Sextupole	1152	0.2	40	40	85T/m²		10%	100%	1E-03	1.0E-03	0.1	0.1
MB1	Dipole	184	1.5	80	80	1.6T		10%	100%	1E-03	1.0E-04	42.0	7.7
MB2	Dipole	32	0.7	80	80	1.6T		10%	100%	1E-03	1.0E-04	25.0	0.8
MB3	Dipole	236	1	80	80	0.26T		10%	100%	1E-03	1.0E-04	4.5	1.1
MBCO	Dipole	1061	0.2	80	80	0.07T		-100%	100%	1E-03	1.0E-03	0.4	0.4
Q1	Quadrupole	1061	0.5	80	80	14T/m		10%	100%	1E-03	1.0E-04	5.9	6.3
SX	Sextupole	416	0.2	80	80	85T/m²		10%	100%	1E-03	1.0E-03	0.5	0.2
SX2	Sextupole	236	0.5	80	80	360T/m²		10%	100%	1E-03	1.0E-04	3.3	0.8
QLINAC	Quadrupole	1638	0.25	87	87	17T/m		No data	100%	No data	No data	6.3	10.3
MBCO2	Dipole_CO	880	1	200	200	0.008T		-100%	100%	2E-03	2.8E-05	0.3	0.3
Q4	Quadrupole	880	1	200	200	0.14T/m		10%	100%	2E-03	2.8E-05	0.5	0.5

We should look preferably for: the higher power consumers, not too high strength, large n. of units, limited tunability requirement, standard field quality,…

SAVING POWER CONSUMPTION: ZEPTO approach for QUAD

- Since 2010 STCF (Daresbury Laboratory) is working on the development of PM based designs for some families of CLIC magnets. Hybrid (PM + EM) design were also investigated but the retained solutions for the prototypes built or under construction have a full-mechanic tunability system. They were named ZEPTO magnet prototypes (for Zero-Power Tunable Optics).
- The first studied case (the most interesting as concerning the power consumption) was the **Drive Beam Quadrupoles** case (**41400** quadrupoles for an estimated EM consumption of: **8 – 17 MW**).





Cost and power updates foreseen

A WBS based bottom up costing and power estimate, for drive-beam and klystron based machines, will be done for the Project Plan in by end 2018.
Power and cost related studies that are expected to make significant changes:

Action (X = significant impact expected)	Cost	Power/Energy	Comments
Structure/parameters optimisation, minor other changes	X	X	Ok for now, 380 GeV, 1.5 10^34
Further possibility: lower inst. luminosity or initial energy (250 GeV)	X	X	Integrated lum. goal can be maintained
Known corrections needed for injectors and Cooling/Ventilation	X	X	Combination of over-estimates and average vs max in CDR
Structure manufacturing	X		Optimise, remove steps, halves
High eff. Klystrons and RF distribution	X	X	Technical studies where gains can be large
Magnets	?	X	Technical studies
Running scenario (daily, weekly, yearly)		X (energy, cost)	Take advantage of demand changes
Commercial studies, currencies and reference costing date	X	X	Examples: klystrons, CHF, CLIC and FCC will use similar convention

LCC and CLIC

ILC and CLIC: cost comparison for 250 GeV requested (in 6 months)

- From summary of Nakada (ICFA-LCB meeting in Valencia):

  Work for the August LCB meeting
  - *Cost of Phase-one 250 GeV machine:*
    - *Based on the "ILC technology" (with some options) and a normal conducting technology version for a comparison purpose*
  - *Re-assessing physics of a 250 GeV machine*
  - *Further dialog with the community on a staged approach*
  - *Try to understand vary carefully and realistically what means "affordable"*

  ⇒ For defining "the Phase-one machine"
  - *and LCC budget*

- This study will be done (was anyway foreseen for 380 GeV machine so will be the same) but we will not be able to resolve all details by that date.
- Doing some serious work on the klystron option costing is anyway starting (uncertainties today are very large) and we need this effort to understand minimum and cross-over point (indenpently of LCC)

Klystron version (380 GeV)

First look at costs – preliminary

High-efficiency klystron work
very promising – not yet included

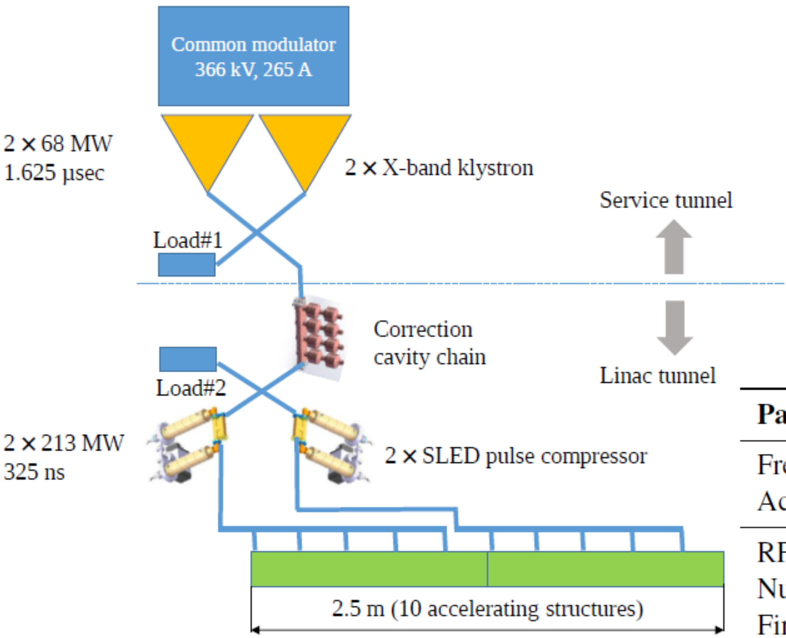


Table 12: The parameters for the structure designs that are detailed in the text.

Parameter	Symbol	Unit	DB	K	DB244	K244
Frequency	f	GHz	12	12	12	12
Acceleration gradient	G	MV/m	72.5	75	72	79
RF phase advance per cell	$\Delta\phi$	°	120	120	120	120
Number of cells	N_c		36	28	33	26
First iris radius / RF wavelength	a_1/λ		0.1525	0.145	0.1625	0.15
Last iris radius / RF wavelength	a_2/λ		0.0875	0.09	0.104	0.1044
First iris thickness / cell length	d_1/L_c		0.297	0.25	0.303	0.28
Last iris thickness / cell length	d_2/L_c		0.11	0.134	0.172	0.17
Number of particles per bunch	N	10^9	3.98	3.87	5.2	4.88
Number of bunches per train	n_b		454	485	352	366
Pulse length	τ_{RF}	ns	321	325	244	244
Peak input power into the structure	P_{in}	MW	50.9	42.5	59.5	54.3
Cost difference (w. drive beam)	$\Delta C_{w.\ DB}$	MCHF	-50	(20)	0	(20)
Cost difference (w. klystrons)	$\Delta C_{w.\ K}$	MCHF	(120)	50	(330)	240

Breakdown of project for cost

Row	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1															
2	**CLIC cost estimate - 500 GeV - CDR**														
4	*Last update:*		1-Sep-15												
5	*ref. EDMS:*		918792												
6															
7	level 0	level 1		level 2		level 3			level 4		Quantity	level 5	Quantity	level 6	Quantity
1068		3	Two-beam accelerators												
2032		4	Interaction Region												
2199		5	Infrastructure and Services												
2370		6	Machine Control and Operational Infrastructure												
2401															

level 3			level 4		Quantity	level 5
1.1.1.	Thermoionic gun unpola	1				
			1.1.1.1.	RF System	1	
			1.1.1.2.	RF Powering System	1	
			1.1.1.3.	Vacuum System	1	
			1.1.1.4.	Magnet Powering Syste	1	
			1.1.1.5.	Magnet System	1	
			1.1.1.6.	Cooling System	1	
			1.1.1.7.	Beam Instrumentation S	1	
			1.1.1.8.	Supporting System	1	
			1.1.1.43.	Survey and Alignment	1	
			1.1.1.19.	Installation	1	
			1.1.1.20.	Commissioning	1	
			1.1.1.21.	DC Power Distribution S	1	
1.1.8.	Bunching System e- for	1				
			1.1.8.1.	RF System	1	
			1.1.8.2.	RF Powering System	1	
			1.1.8.3.	Vacuum System	1	
			1.1.8.4.	Magnet Powering Syste	1	
			1.1.8.5.	Magnet System	1	
			1.1.8.6.	Cooling System	1	
			1.1.8.7.	Beam Instrumentation S	1	
			1.1.8.8.	Supporting System	1	
			1.1.8.43.	Survey and Alignment	1	
			1.1.8.19.	Installation	1	
			1.1.8.20.	Commissioning	1	
			1.1.8.21.	DC Power Distribution S	1	
1.1.2.	Primary e- Beam Linac f	1				
			1.1.2.1.	RF System	1	
			1.1.2.2.	RF Powering System	1	
			1.1.2.3.	Vacuum System	1	
			1.1.2.4.	Magnet Powering Syste	1	
			1.1.2.5.	Magnet System	1	
			1.1.2.6.	Cooling System	1	
			1.1.2.7.	Beam Instrumentation S	1	
			1.1.2.8.	Supporting System	1	
			1.1.2.43.	Survey and Alignment	1	
			1.1.2.19.	Installation	1	
			1.1.2.20.	Commissioning	1	
			1.1.2.21.	DC Power Distribution S	1	

Lots of work ahead

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Power and cost related studies that are expected to make significant changes:

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Running scenario (daily, weekly, yearly)		X (energy, cost)	Take advantage of demand changes
Commercial studies, currencies and reference costing date	X	X	Examples: klystrons, CHF, CLIC and FCC will use similar convention

Project Organisation

Over the last year the LC study organisation has changed in preparation of the European Strategy Update report. We put more emphasis on implementation studies related to the entire CLIC machine.

We still have the project organised in four main activities, each with a group of individual WPs and WP leaders:

1. Beamdynamic and design - D.Schulte
2. X-band included high off klystron studies - W.Wuensch
3. Linac systems: Main Linac module and Drive Beam front end - S.Doebert
4. Technical systems and studies - N.Catalan

General work-packages and budgets – S.Stapnes:

The studies at ATF2 and in light sources are WPs under General activities. ILC/LCC support activities likewise.

CTF3 closedown and CLEAR preparation are also under this general heading with WPs lead by R.Corsini.

Five new implementation working groups preparing for the ESU have been started (https://indico.cern.ch/category/4337/) – some of which also existed ahead of the CDR in 2012:

1. Civil Engineering & Infrastructure and Siting WG (CEIS) (lead J.Osborne) (mandate)
2. Cost, Power and Schedule (lead S.Stapnes) (Detailed costing of a 380 GeV machine - DB and klystrons - plus additional stages beyond)
3. Main Linac Hardware Baselining (lead C.Rossi) (Optimised module technical design and surrounding infrastructure in the tunnel, considering the entire lifetime of a module including commissioning, installation, conditioning, operation, rework, replacements etc.)
4. Baseline parameters and design (lead D.Schulte) (Designs and parameters for 380 (DB and klystrons) GeV, 1.5 TeV and 3 TeV)
5. Novel Accelerator methods for future stages of CLIC (lead E.Adli) (mandate)

The WGs have ~10-15 core members as needed to cover the subject, and meet every 4-6 weeks in open meetings (to all coll. members). Costing meetings are closed.

See implementation meetings every Friday 9-11 at indico link above.