DESIGN CHOICES FOR THE KLYSTRON AND DRIVE BEAM BASED CLIC MAIN LINAC MODULES

LCWS 2017 – 26th October 2017 - C. Rossi

OUTLINE

- The CLIC Implementation Studies
- Main Linac Hardware WG
- CLIC Module WG Activities
- Plans for the Near Future
- Perspectives in the Longer Term

The CLIC Implementation Studies

The CLIC Implementation WGs started to meet in September 2016 .

CLIC Design - *lead by D. Schulte*;

CLIC Main Linac Hardware Baselining - *lead by H. Schmickler* (C. Rossi as from January 2017);

CLIC Civil Engineering & Infrastructure and Siting - *lead by J. Osborne*;

CLIC Cost and Power - *lead by S. Stapnes*.

GOALS:

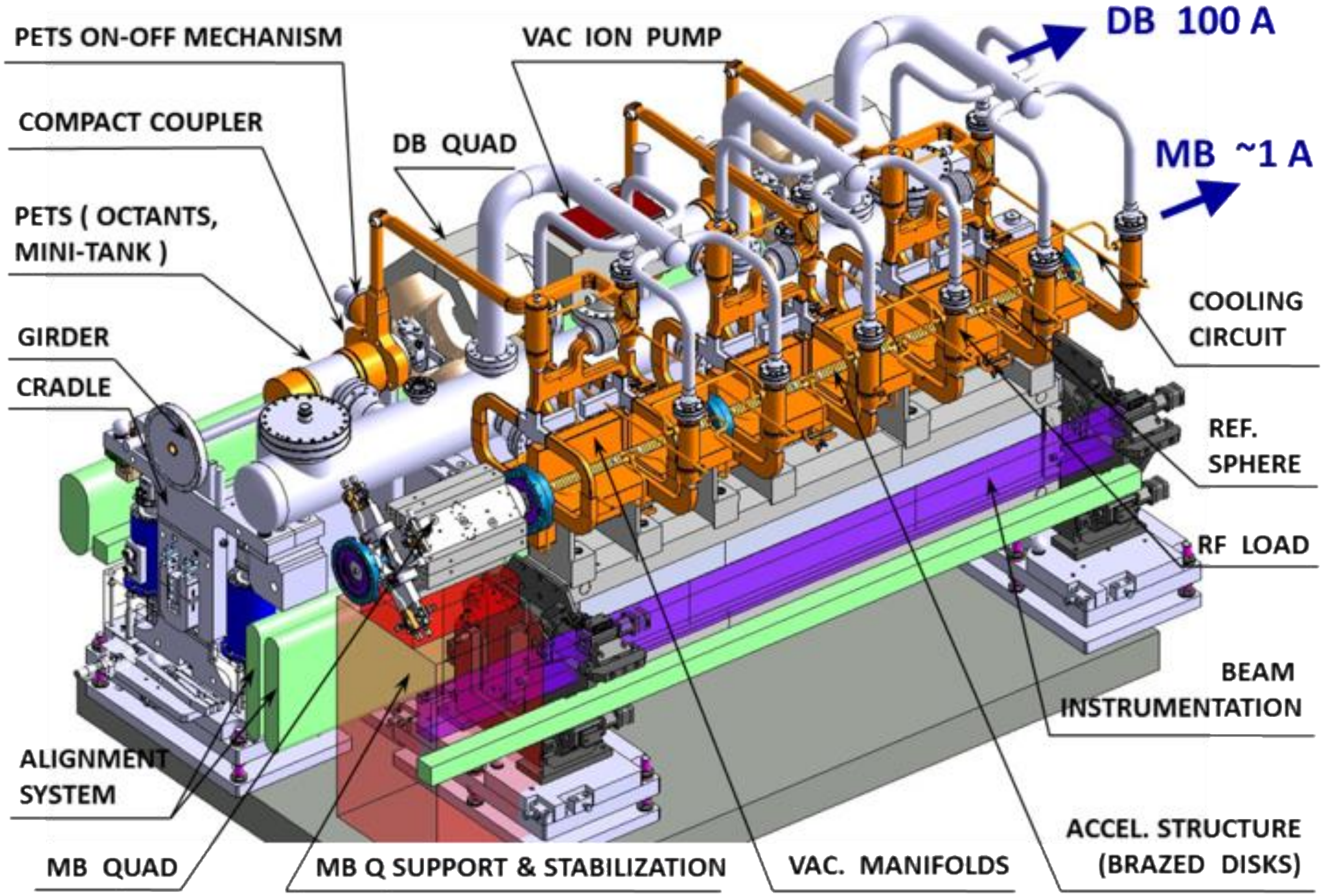
Focus the attention on the 380 GeV stage and consider all options;

Increase the exchange of information and synergies among the different study areas of CLIC;

Prepare the next update of the European Strategy document.

CLIC Main Linac Hardware Baselining

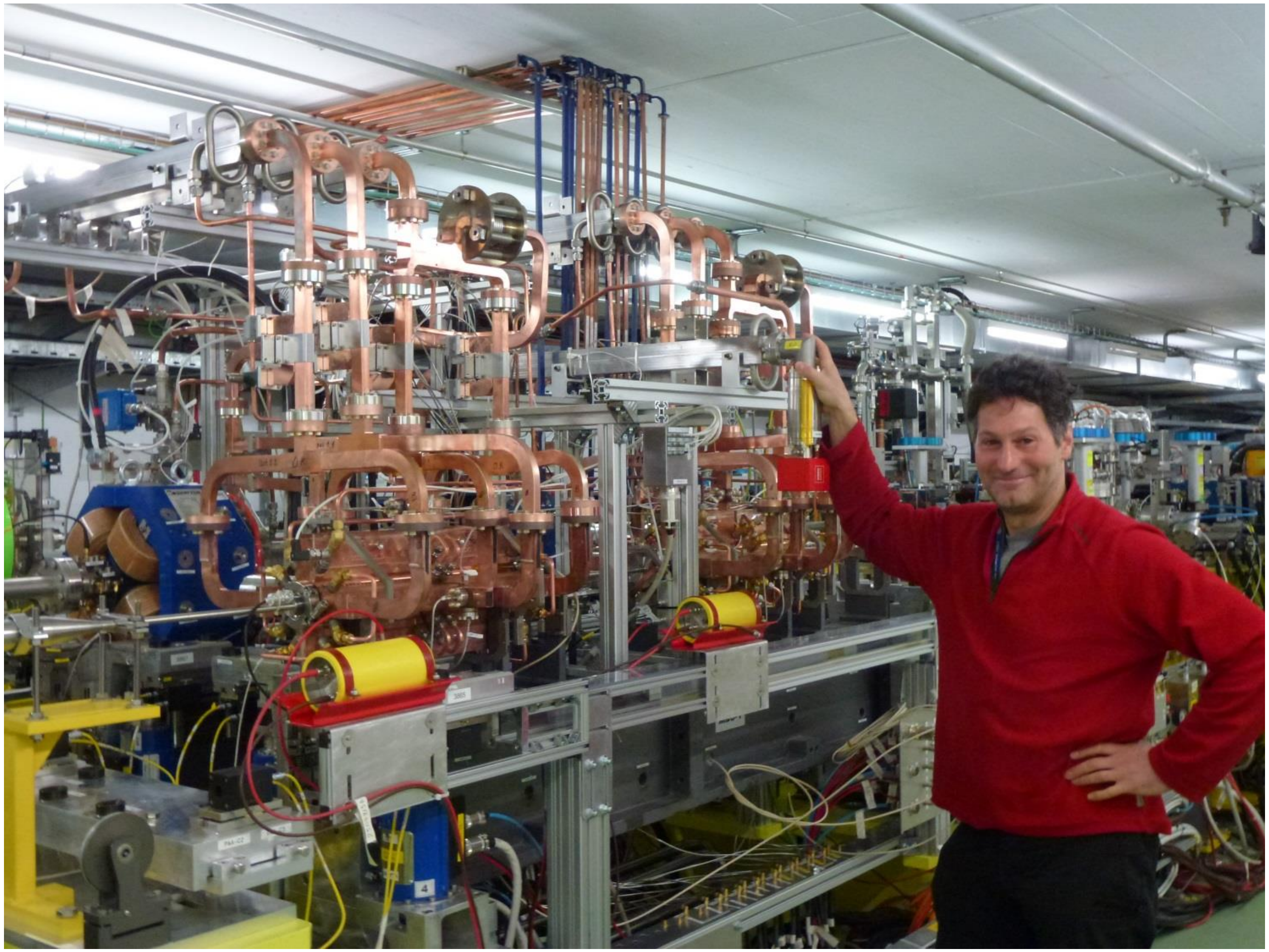
Attention has focused on the so-called CLIC Module, its environment and lifecycle.



CLIC Main Beam Module as described in the CLIC CDR (CERN-2012-007)

CLIC Main Linac Hardware Baselining

The CLIC Module, as installed in the CLEX facility.



For results see W. Farabolini's presentation at CLIC Workshop 2017.

CLIC Main Linac Hardware Baselining

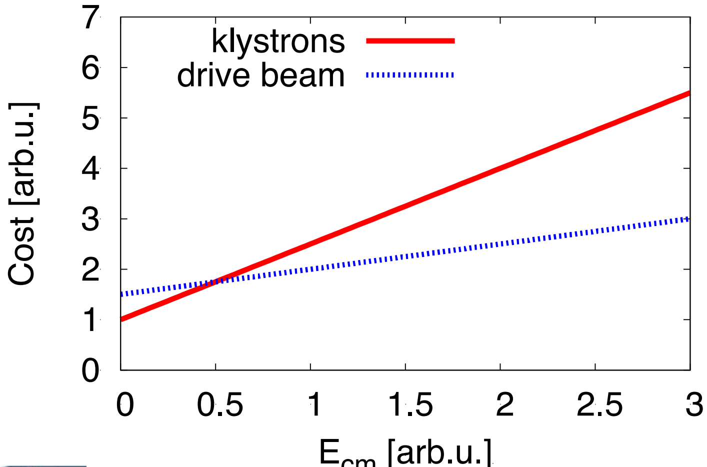
Main goals:

Reconsider all aspects of the CLIC design, impacting on the CLIC Module layout;
Bring the main actors together and stimulate reciprocal exchanges to progress with the Module optimization.

Beam dynamics optimized at 380 GeV for the two cases: klystron and drive beam.

Mechanical tolerances and pre-alignment requirements reconsidered, also to the light of PACMAN's achievements.

Stronger collaboration work with the RF design team for the definition of the klystron-based module.



With the increase of the klystron and modulator efficiencies, the interest for a low energy stage driven by klystrons is growing.

Based on a semi-analytical model. To be reviewed with recent cost figures and updated models.

CLIC Main Linac Hardware Baselining

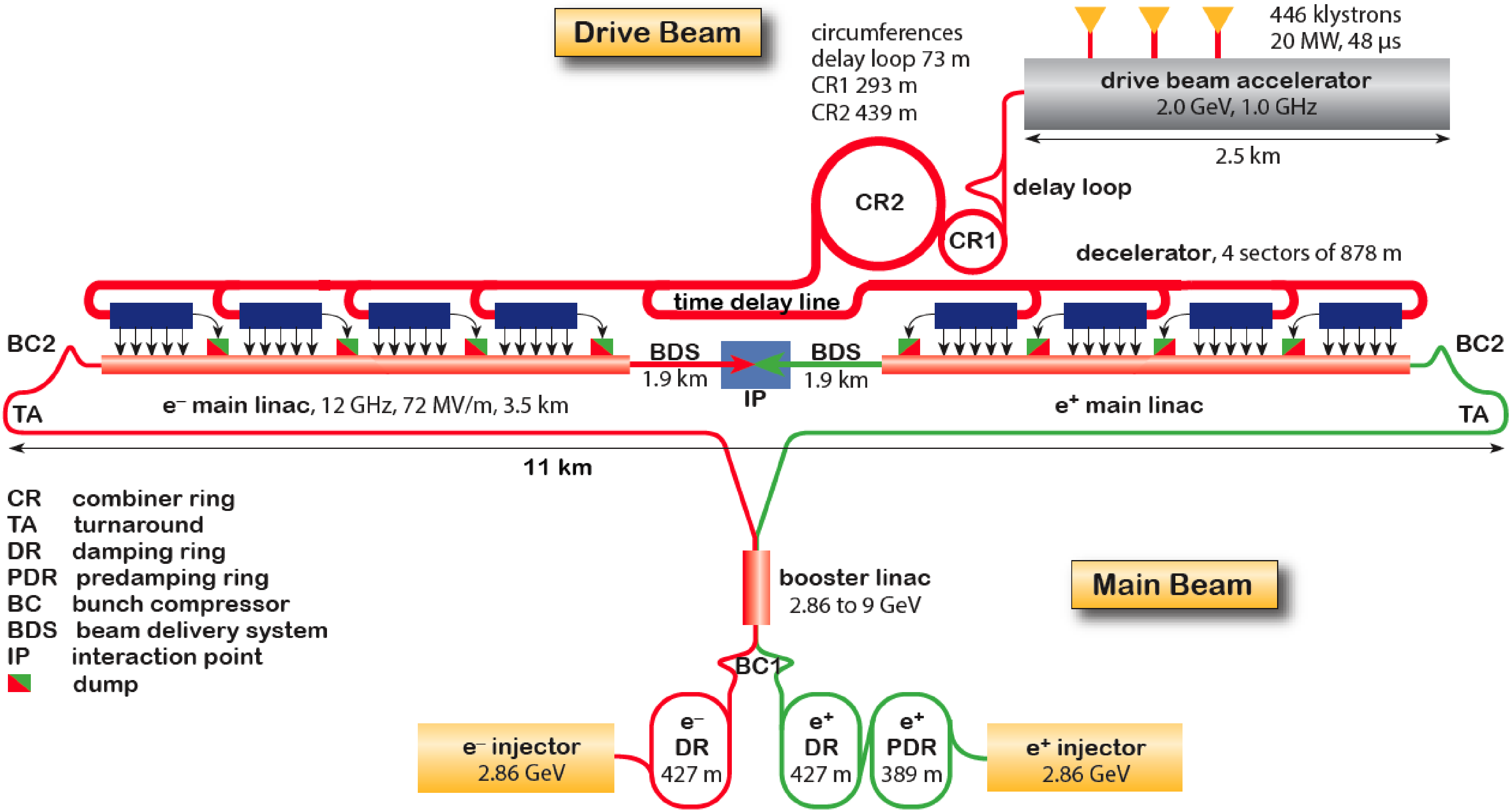
New reference parameters for the RF Design on the basis of beam dynamics requirements
Optimized parameters have been provided for the two options - *D. Schulte, November 2016.*

Parameters	units	DB	K
Frequency	GHz	12	12
Gradient	MV/m	72	75
Cells/structure		33	28
Particles/bunch	10^9	5.2	3.87
Bunches/train		352	485
Pulse length	ns	244	325
RF Power (peak)	MW	59.5	42.5

With constant Luminosity = 1.5 10^{34} cm^{-2} s^{-1}

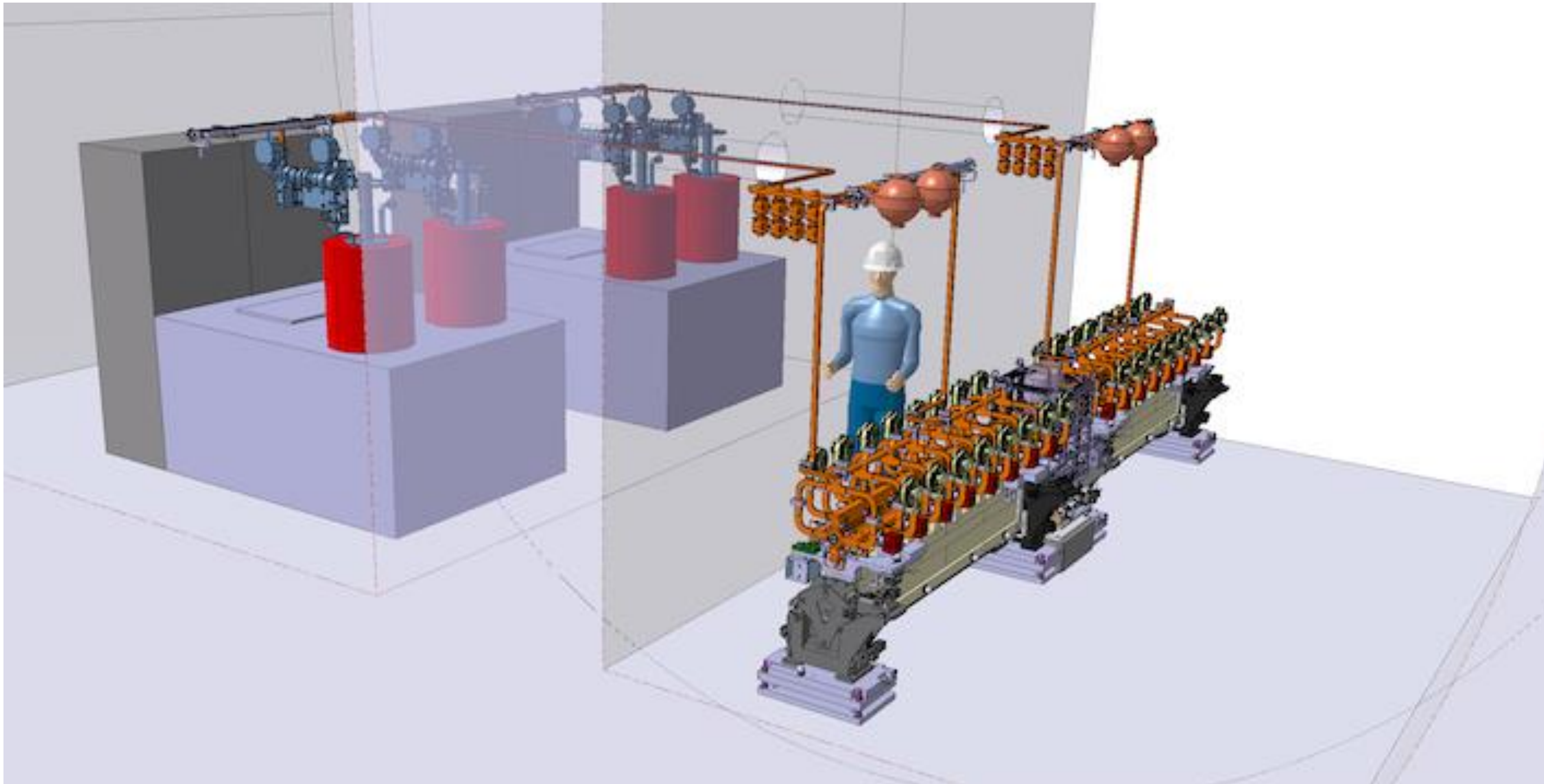
CLIC two beam accelerator at 380 GeV

DB option optimized for the 380 GeV stage (in *Updated baseline for a staged Compact Linear Collider*, CERN – 2016 – 004).



380 GeV K-based module layout and tunnel integration

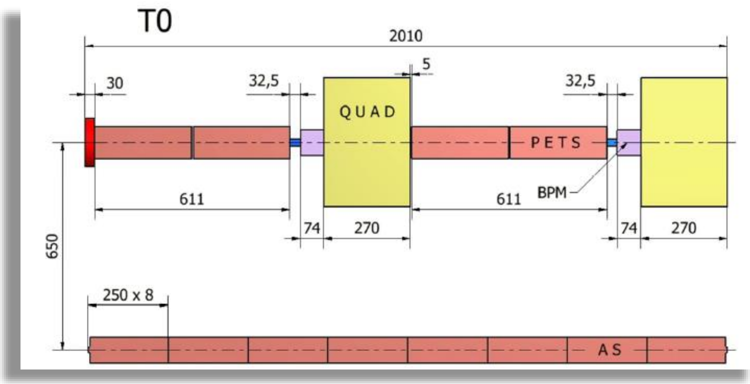
Klystron option for the 380 GeV stage. The tunnel integration is under study, see presentation by M. Stuart and J. Osborne.

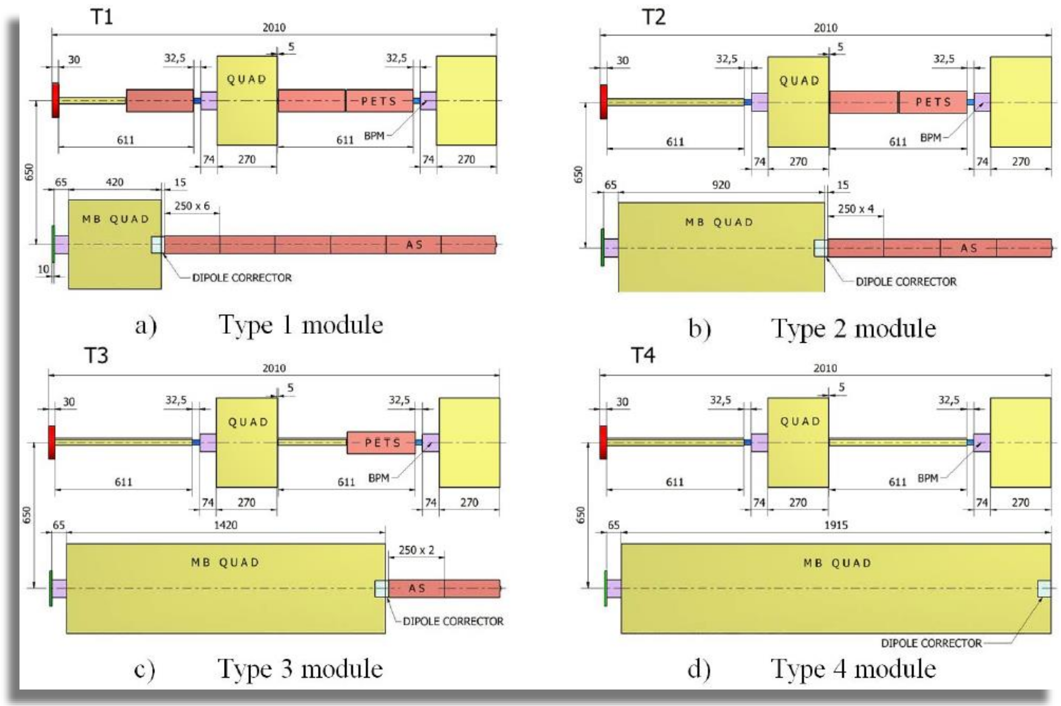


Courtesy Y. Cuvet

CLIC Main Linac Hardware Baselining

The CLIC CDR proposal was considering a mix of different Module layouts to adapt to the requirements of the Main Beam and Drive Beam lattices.





At 3 TeV there are 73% of T0, 3% of T1, 12% of T2, 9% of T3 and 3% of T4.

The CLIC Module is 2 m long in the present design.

Studies looking at the Main Beam Quadrupole stabilization problem have shown that an independent support is required to guarantee the level of stability requested by the challenging beam dynamics.

380 GeV Module Sequence - Klystron Option

Sectors of the Main Beam FODO lattice for one Linac

FODO Sector	T0	Q1	Q2	Totals	AS with 28 cells
1	148	148			sequence: 148 x T0Q1
2	276	138			sequence: 138 x T0T0Q1
3	228	76			sequence: 76 x T0T0T0Q1
4	300		100		sequence: 100 x T0T0T0Q2
5	504		126		sequence: 126 x T0T0T0T0Q2
Totals	1456	362	226		
Quads	0	362	226	588	
AS	11648			11648	

T0 Module is made of 8 x AS

Q1 is 0.4 m and Q2 is 0.65 m long

The Length of each Linac = 3334 m

380 GeV Module Sequence – Drive Beam Option

Sectors of the Main Beam FODO lattice for one Linac

FODO Sector	DB Sector	T0	T1	T2	Totals	AS with 33 cells
1	1		120		120	sequence: 120 x T1
2	1	150	150		300	sequence: 150 x T0T1
3	1	16	8		24	sequence: 8 x T0T0T1
	Totals	166	278	0	444	
3	2	156	78		234	sequence: 78 x T0T0T1
4	2	124		62	186	sequence: 62 x T0T0T2
5	2	3		1	4	sequence: 2 x T0T0T0T2
	Totals	283	78	63	424	
5	3	321		107	428	sequence: 107 x T0T0T0T2
	Totals	321		107	428	
5	4	126		42	168	sequence: 41 x T0T0T0T2
6	4	16		4	20	sequence: 4 x T0T0T0T0T2
	Totals	142	0	46	188	
Totals		912	356	216	1484	
Quads		0	356	216	572	356 x 0.35 + 216 x 0.85
AS		7296	2136	864	10296	

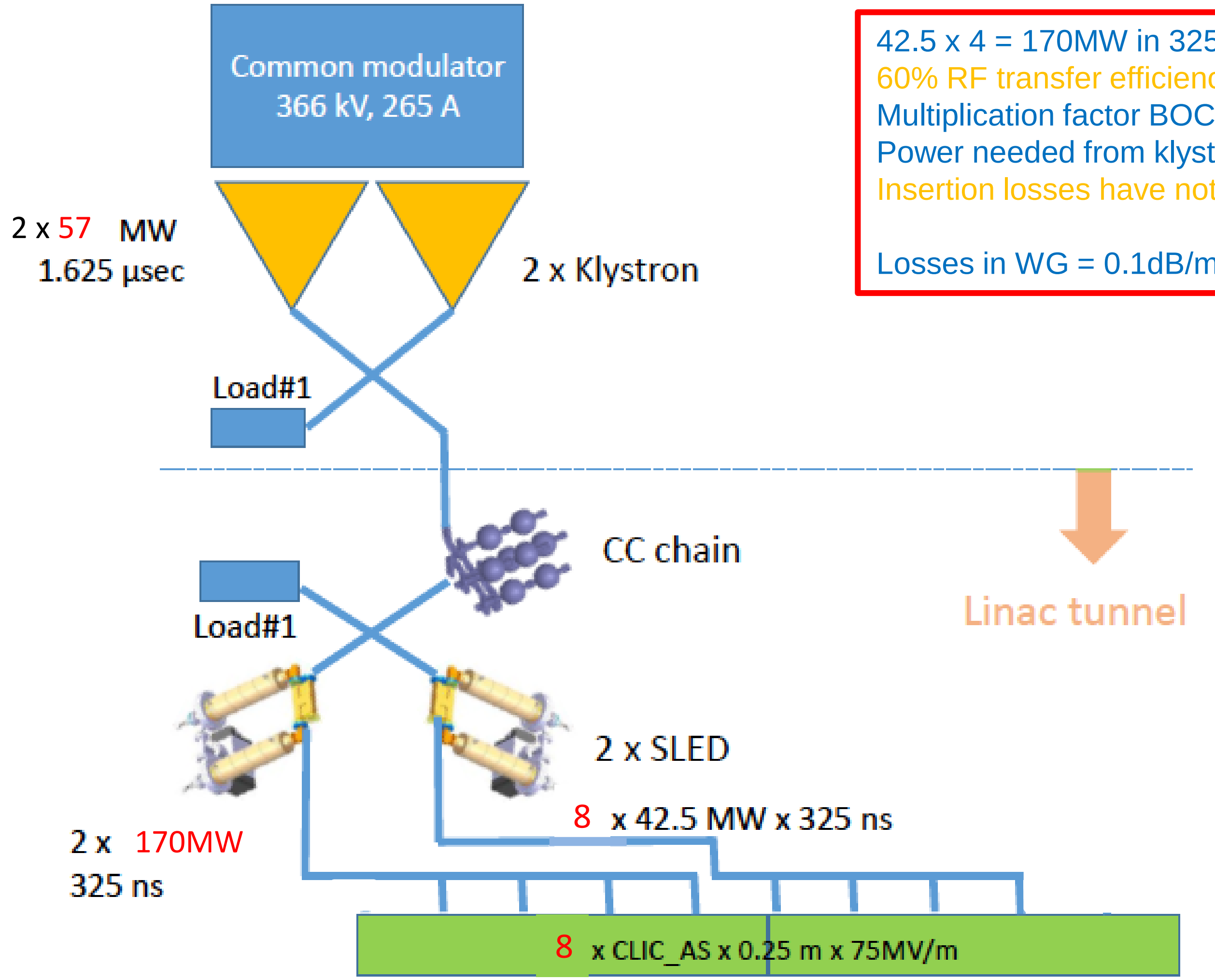
RF Efficient Design

Structure	CLIC-G*	CLIC380	Klystron (K)
f_{rep} [Hz]	50	50	50
Efficiency: η [%]	28.5	39.8	38.7
Rise time: tr [ns]	22	13.1	20.3
Filling time: tf [ns]	65.5	55.4	62.7
Efficient beam loading time: tb [ns]	155.5	175.5	242
Pulse length: tp [ns]	243	244	325
P_{in} [MW]	62.3	59.7	41.7
$P_{out}^{unloaded}$ [MW]	26.5	27.6	17.9
P_{out}^{loaded} [MW]	9.76	6.2	4.5
P_{beam} [MW]	27.747	33.035	21.673
Thermal dissipation [W]: $\langle P_{dissipated}^{unloaded} \rangle$, $\langle P_{dissipated}^{loaded} \rangle$	434.970, 349.394	391.620, 289.526	386.750, 286.649
Mean power in the load [W]: $\langle P_{load}^{unloaded} \rangle$, $\langle P_{load}^{loaded} \rangle$	321.975, 191.822	336.720, 148.935	290.875, 128.735
Mean power to the beam: $\langle P_{beam} \rangle$ [W]	215.729	289.879	262.241

A. Grudiev and X. X. Huang 5/04/17

380 GeV K-based powering scheme

Example of RF Distribution as presented by I. Syratchev on 21/01



42.5 x 4 = 170MW in 325ns out of BOC
60% RF transfer efficiency of BOC + waveguides
Multiplication factor BOC = 5
Power needed from klystron = 57MW in 1.625μs
Insertion losses have not been considered

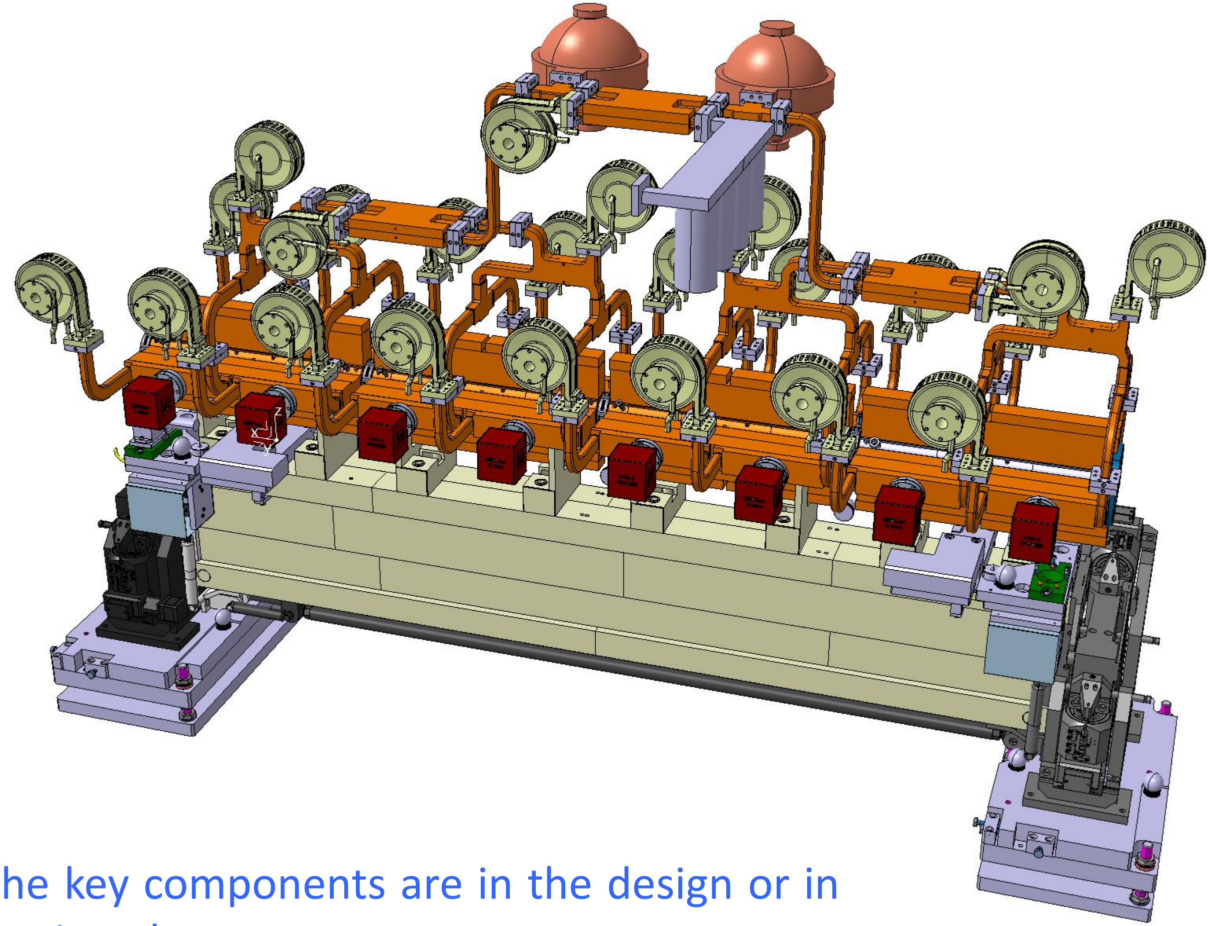
Losses in WG = 0.1dB/m, ~ 60 to 100W/m

my numbers in red

I. Syratchev 21/01/17

380 GeV K-based module layout

The preliminary layout of the K-Module has been first defined on the basis of available components.

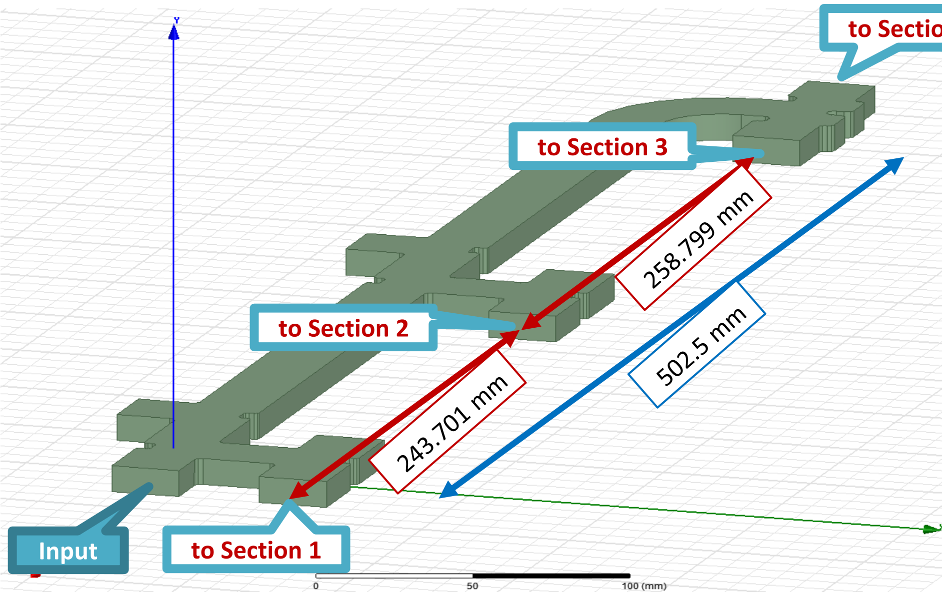


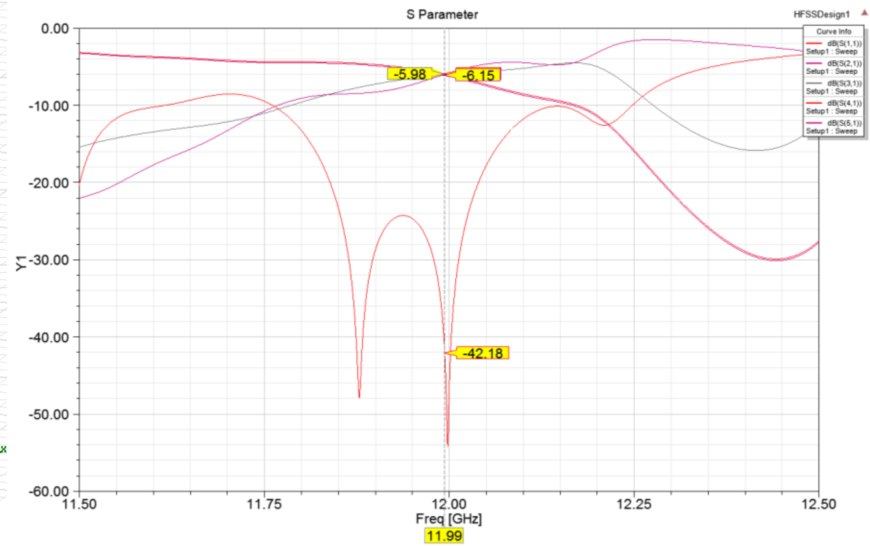
Courtesy Y. Cuvet

Some of the key components are in the design or in the prototyping phase.

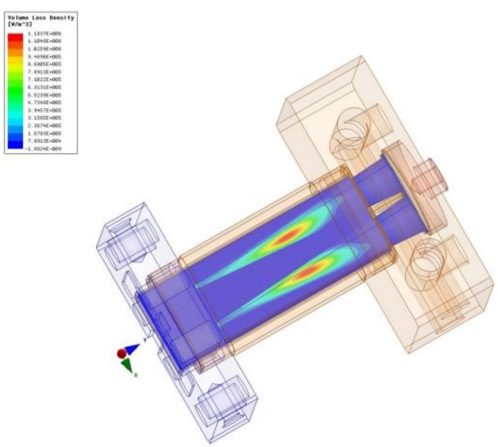
380 GeV module component developments

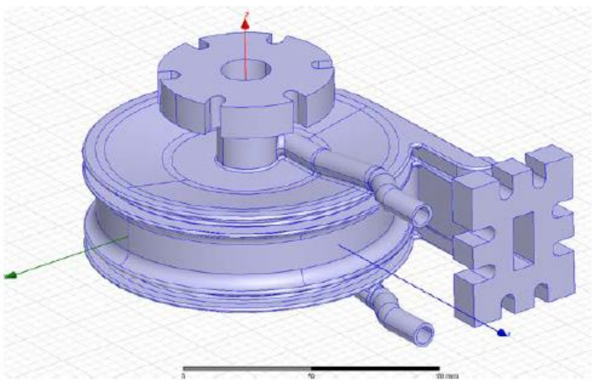
4-way splitter to simplify the RF distribution





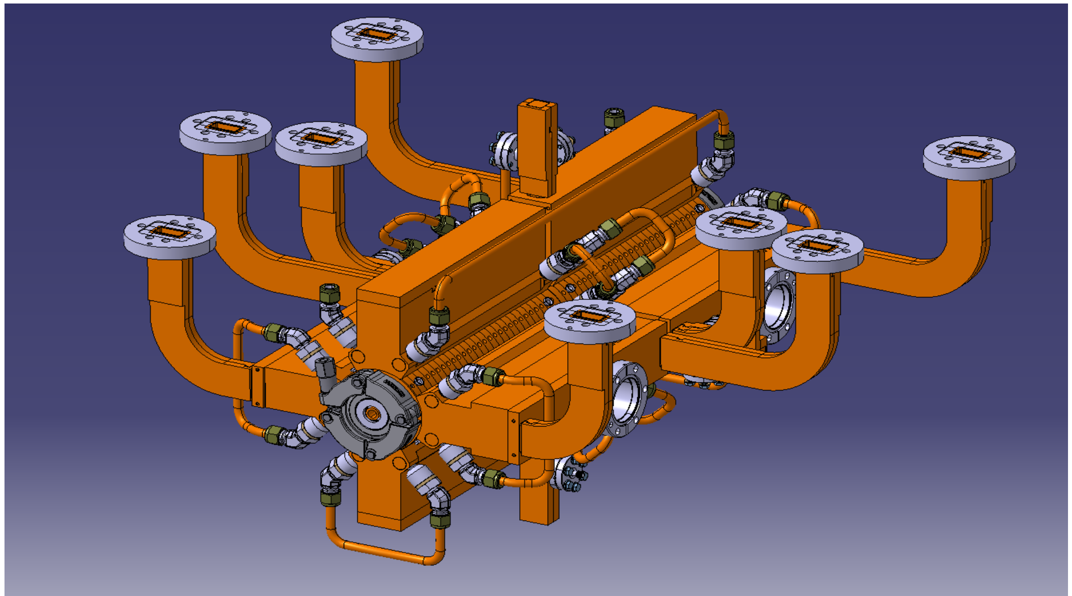
RF compact loads

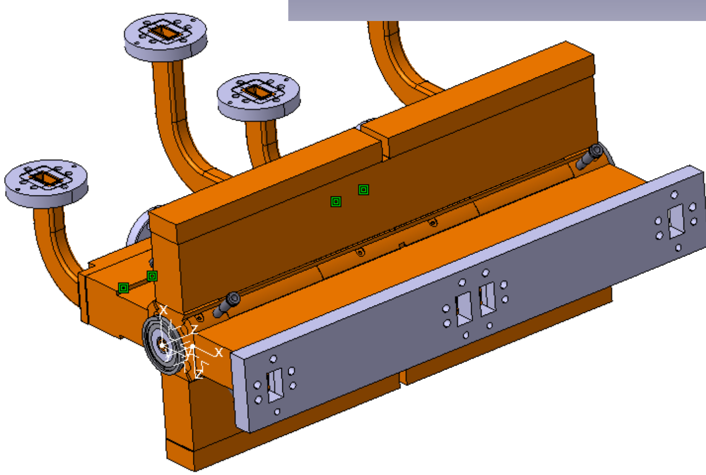


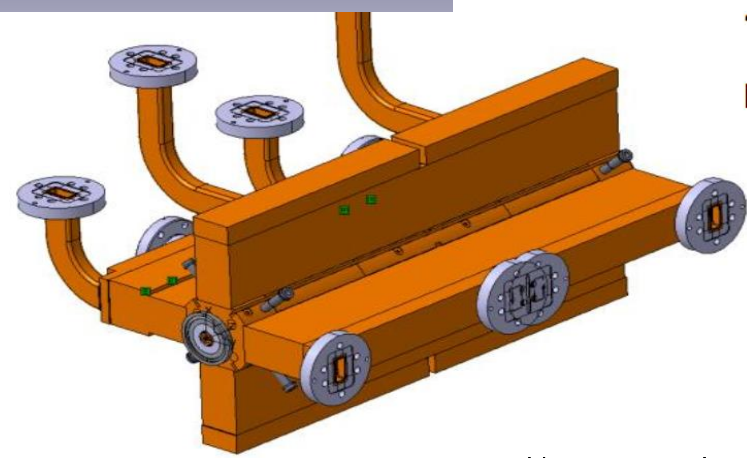


Developments with RF design

The RF design is being refined to improve compactness and integration in the module



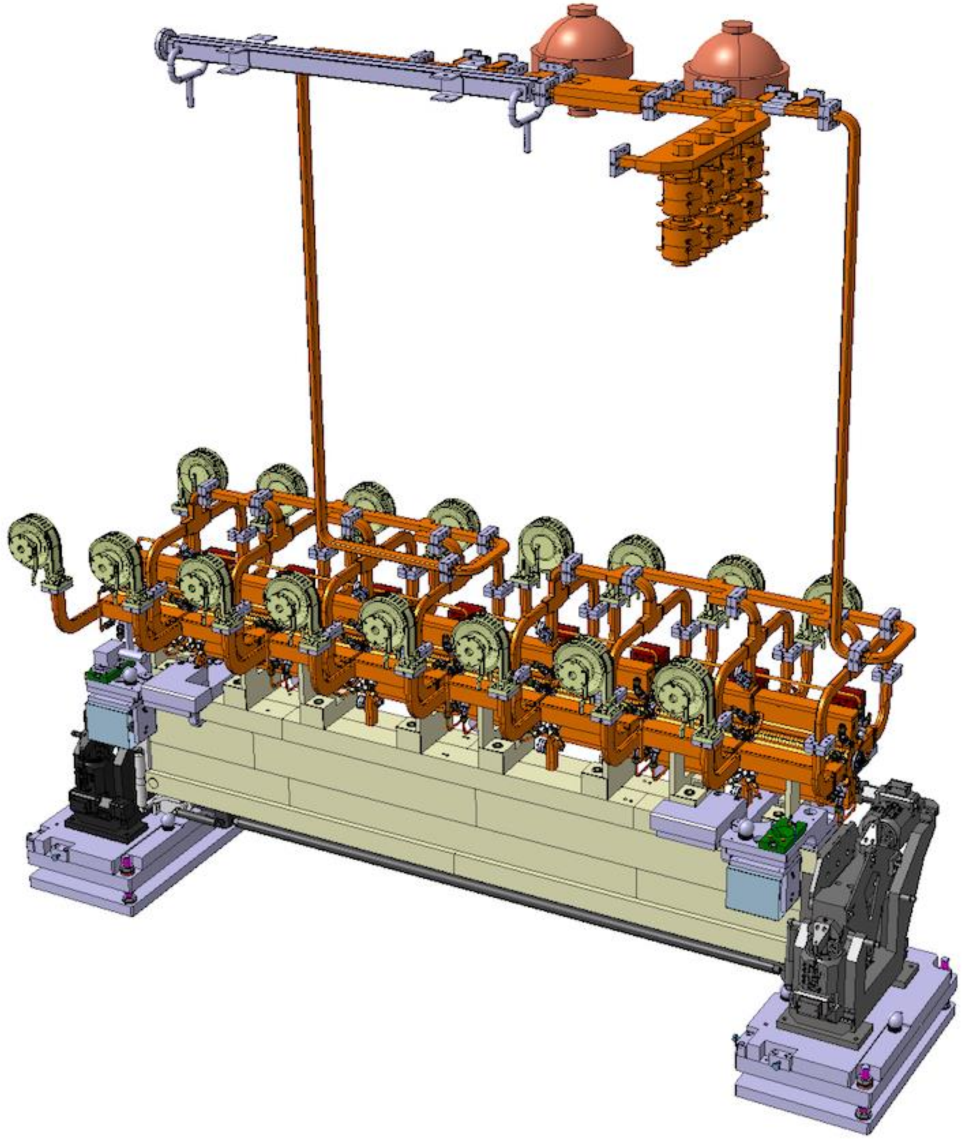




Proposal by A. Vamvakas

380 GeV K-based module developments

The initial layout is being simplified and refined on the basis of integration requirements

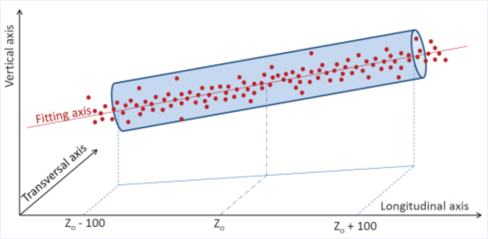


Courtesy Y. Cuvet

CLIC alignment strategy

CDR approach to alignment, with fixed AS supports and relying on the accuracy of the supporting surfaces. See details in H. Mainaud Durand's presentation.

Beam off



Mechanical pre-alignment	~0.2 - 0.3 mm over 200 m
Active pre-alignment	14 - 17 µm over 200 m

Beam on

Beam based Alignment & Beam based feedbacks

One to one steering	Dispersion Free Steering	Minimization of AS offsets
Make the beam pass through	Optimize the position of BPM & quads by varying the beam energy	Using wakefield monitors & girders actuators

→ **Minimization of the emittance growth**

Courtesy H. Mainaud Durand

CLIC alignment strategy

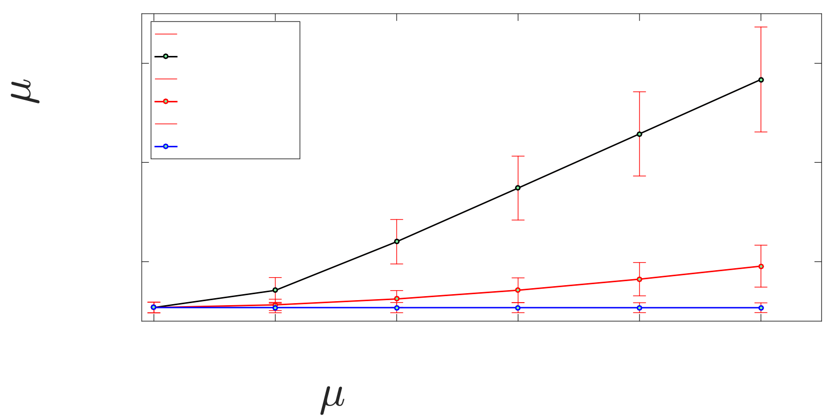
Main Beam alignment

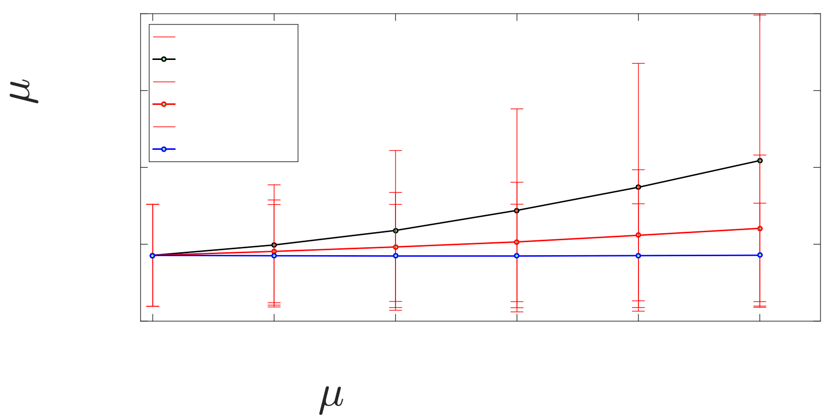
imperfection	with respect to	symbol	value	emitt. growth
BPM offset	wire reference	σ_{BPM}	14 μm	0.367 nm
BPM resolution		σ_{res}	0.1 μm	0.04 nm
accelerating structure offset	girder axis	σ_4	10 μm	0.03 nm
accelerating structure tilt	girder axis	σ_t	200 μradian	0.38 nm
articulation point offset	wire reference	σ_5	12 μm	0.1 nm
girder end point	articulation point	σ_6	5 μm	0.02 nm
wake monitor	structure centre	σ_7	5 μm	0.54 nm
quadrupole roll	longitudinal axis	σ_r	100 μradian	$\approx$ 0.12 nm

Assembly
Pre-alignment
Transport

Courtesy D. Schulte

Drive Beam alignment





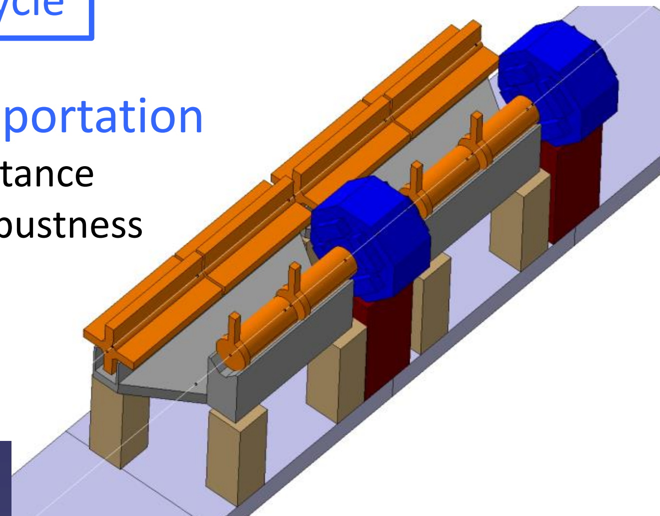
Courtesy X. Meng

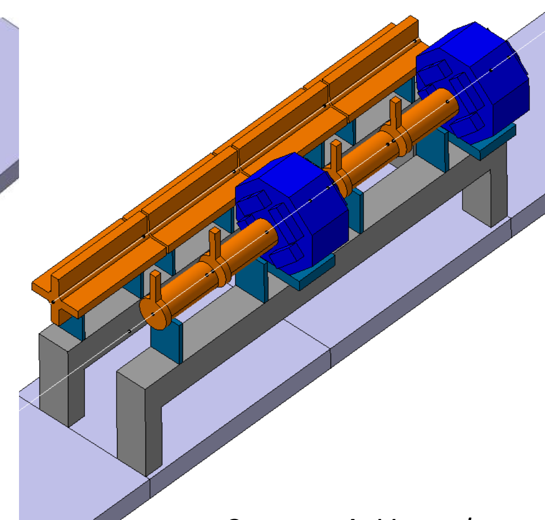
CLIC Module alignment after PACMAN

Considering the Module lifecycle

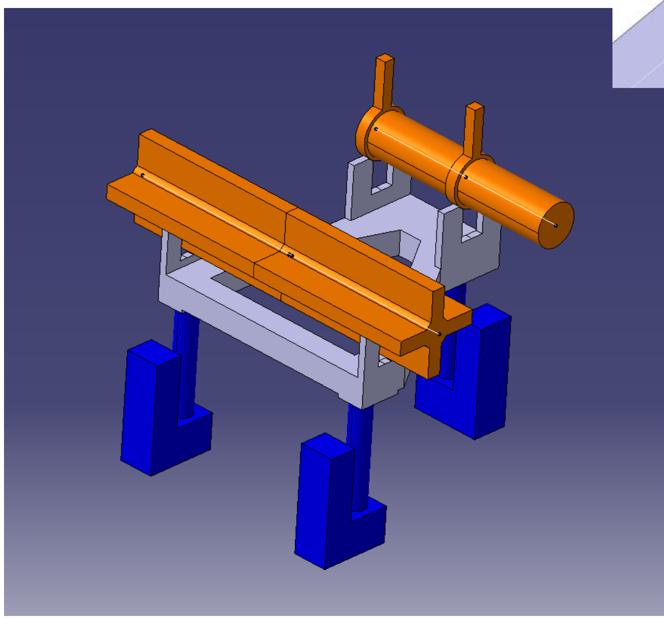
Preparation
- Fabrication (tolerances)
- Assembly and testing
- RF Conditioning

Transportation
- Distance
- Robustness





Courtesy A. Vamvakas



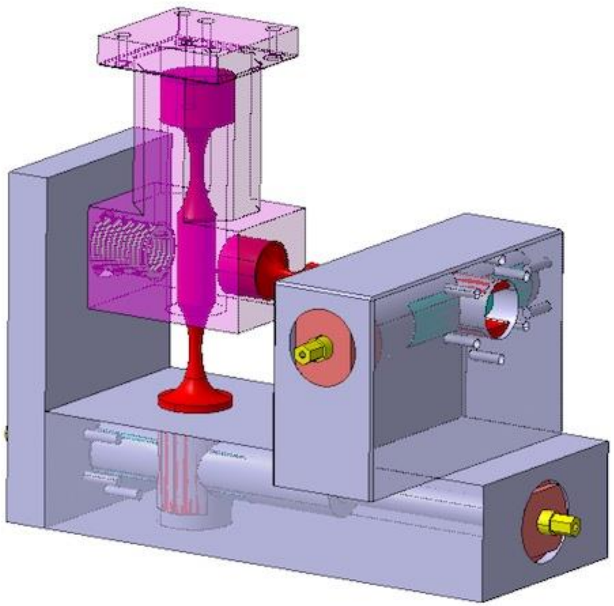
Installation
- Connections
- Vacuum sectors
- Alignment
- Conditioning with beam

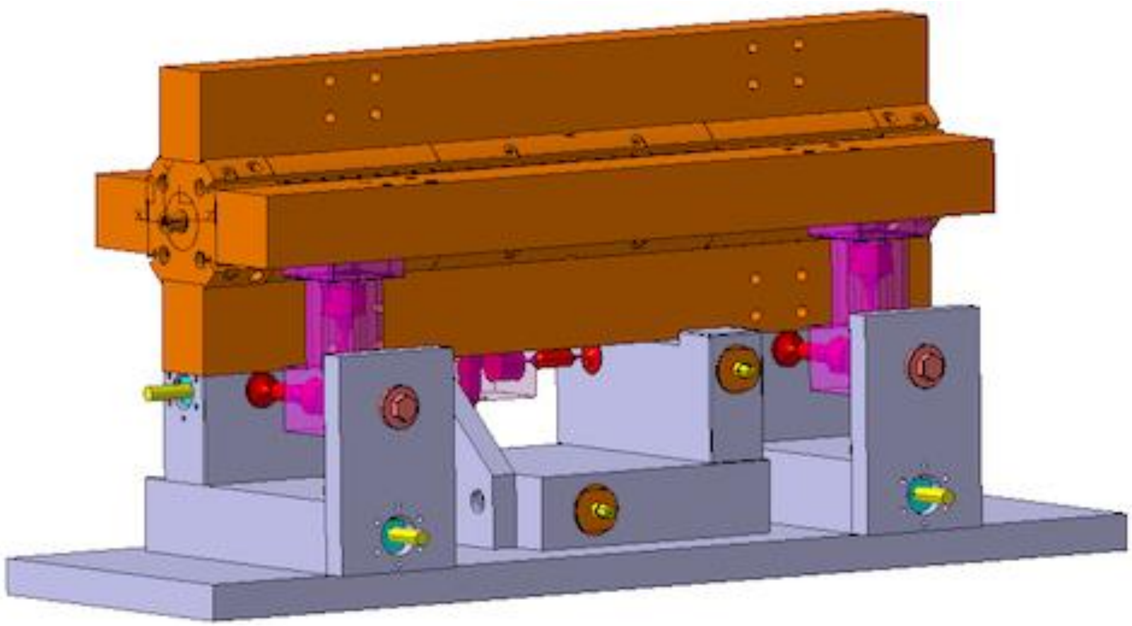
Operation
- Temperature sensitivity
- Transients
- Failure rate + maintenance
- Ground movement
- Human interaction

Adjustability also in the tunnel is important

Developments for the CLIC Module alignment

Assure adjustability of components after installation





Courtesy J. Vainola

Developing adjustable supports that can allow semi-automatic alignment techniques for rapid and very precise adjustment of the component position in the tunnel.

CLIC Module Power Dissipation

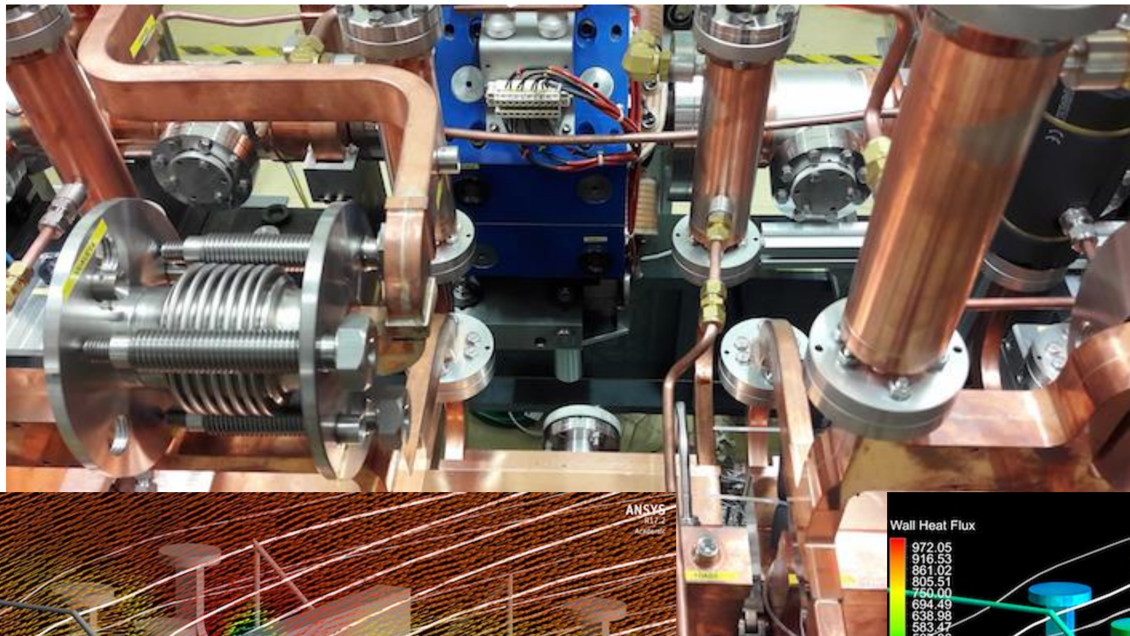
Power dissipation and temperature stabilization are critical. Limiting the heat transfer to air in the tunnel is a requirement. Development work is in progress to clarify the picture.

Component	unit	380 GeV DB	380 GeV K
MBQ	MW	1.9	1.4
DBQ	MW	1.1	0
MB Beam instrumentation	MW	0.015	0.015
DB Beam instrumentation	MW	0.077	0
MBQ stabilization	MW	0.1	0.1
MB AS loaded	MW	9	9.7
MB AS unloaded	MW	15	15.8
DB RF structures	MW	0.91	0
MB klystrons	MW	0	18
MB klystron modulators	MW	0	8

Dissipated in the klystron gallery

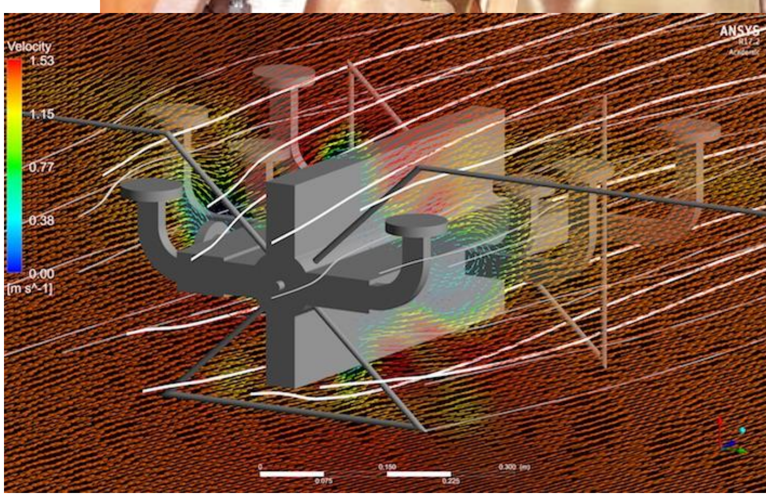
CLIC Module Power Dissipation

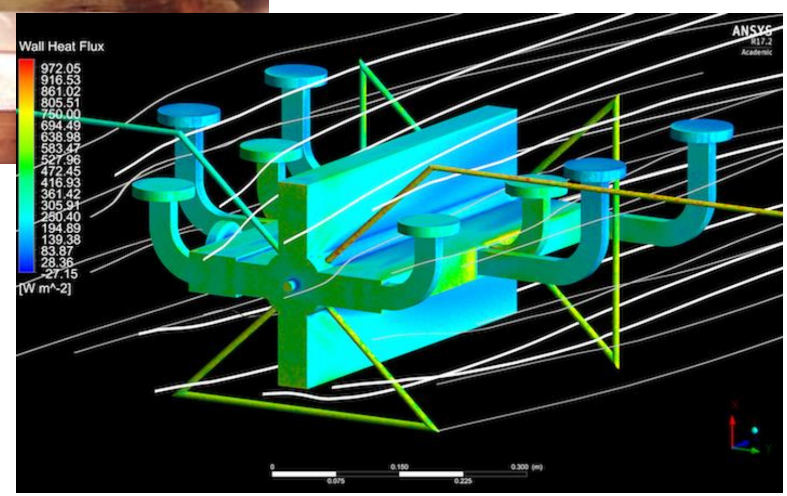
An extensive experimental campaign and heat flux modelizations are used to evaluate the cooling needs and the heat load to air in the accelerator tunnel.



Initial CDR assumption was 150 W/m to air.

Water flows from 1 to 2 l/min.





Courtesy E. Lam

Plans for the near future

In 2017 we want to:

Conclude the CLIC Implementation WG meetings, by producing a new specification for the CLIC Module, becoming the new baseline.

Provide a new design for the CLIC K and DB Module.

Progress with the RF team in the design of the main components required (compact RF loads, hybrids, pulse compressors, etc.).

Work in close collaboration with the Civil Engineering WG, to complete the integration and the infrastructure specification.

Before the end of 2018:

A complete description of the 380 GeV stage will be provided, with emphasis on the klystron option.

A cost estimate will be provided for the 380 GeV stage, in the K and DB configurations.

Perspectives in the longer term

After 2018:

Complete the design phase and build a complete klystron-based module

Develop an X-band test station capable of testing the k-module at nominal field gradient and employing high efficiency components.

Complete the design of a two-beam RF unit (1m Super Accelerating Structure + 2 PETS) and study the details of its realization and installation, including acceptance test and initial commissioning.

Launch industrialization studies and refine the cost and power estimates