Technical requirements and engineering design of the RF structures

A. Samoshkin

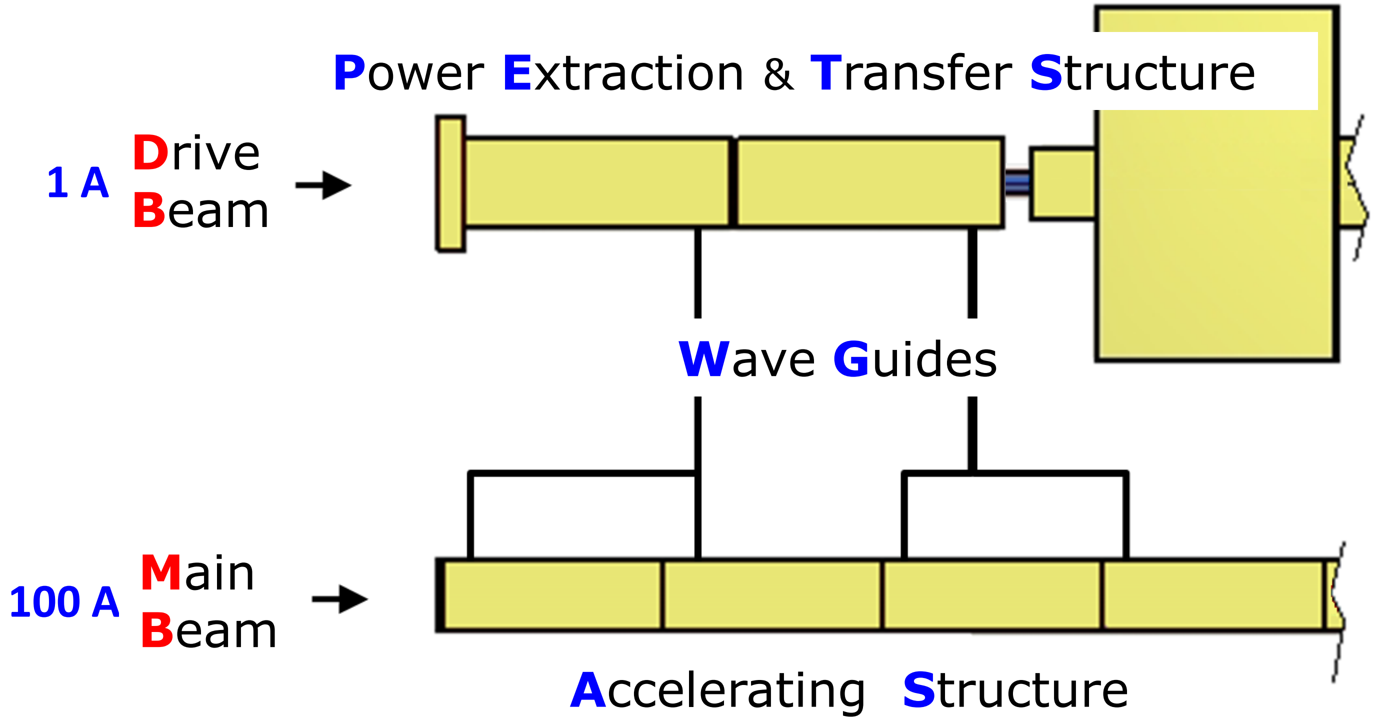
Content

- **Two-beam acceleration:**
  - which components are needed and what do they stand for.
- **The main requirements:**
  - beam requirements;
  - RF design.

  - shape accuracy;
  - tolerances and surface quality;
  - systems
- **Mechanical design:**
  - RF structures prototypes;
  - engineering issues
  - what will be required for the final CLIC RF structures

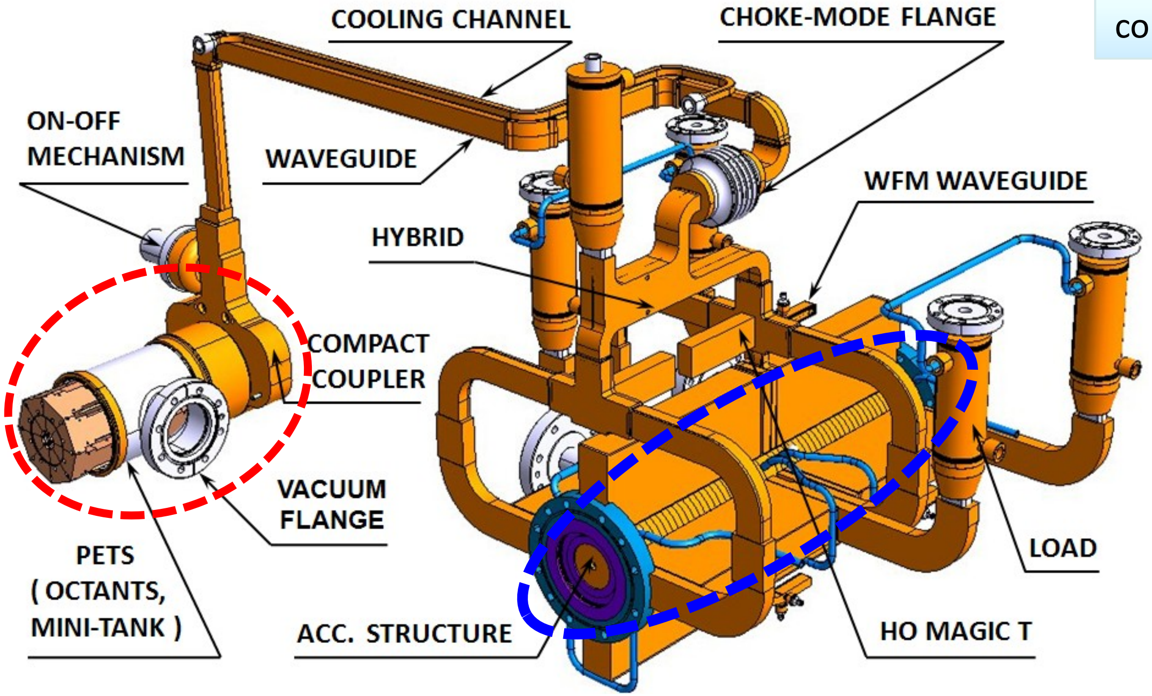
Two-beam acceleration

Alex… …ern.ch



Main RF components

The CLIC two-beam RF network includes the standard X-band rectangular waveguides connecting PETS, AS and other supplementary devices such as choke-mode flange (CMF), Hybrid, high-power load, splitter and WFM.



One PETS feeding two AS

Waveguide length optimization is based on losses, phase advance and RF to beam timing considerations.

The power transmission without electrical contact between two beams, and also MB and DB independent alignment is getting possible with CMF. The Hybrid provides the power to two adjacent AS. The RF load is attached to one of the hybrid ports to avoid the RF reflection to the corresponding PETS. The RF splitters are used to equally feed the AS.

__Requirements:__
tolerance on RF phase change between DB and MB: **± 0.12 deg**
WG interconnections between PETS and AS via CMF:
X – shift: **± 0.25 mm**, Y **± 0.5 mm**, Z **± 0.5 mm**, Twist: **< 5°**

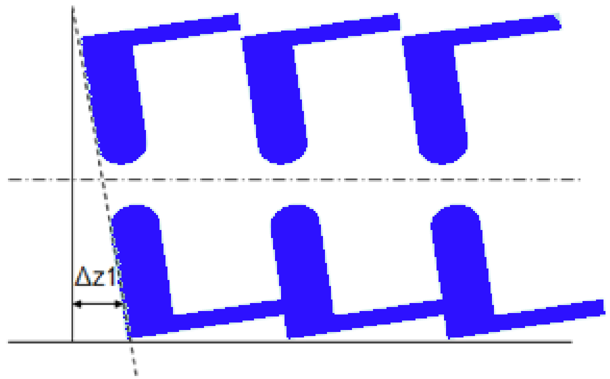
Errors

The micrometer tolerance level is required for the structure components production and a few micrometers for the structure assembly in order to fulfil very stringent beam dynamics requirements.

Phasing: an error in the cell shape determines a wrong phase advance → inefficiency in acceleration

Mismatching: a geometrical error introduces a power reflection → lower efficiency.

Assembly: bookshelf → introduces the transverse kick which is proportional to the accelerating gradient; longitudinal misalignment of half-structure



Structure in disks. Problem mainly for the brazing/bonding (assembly)

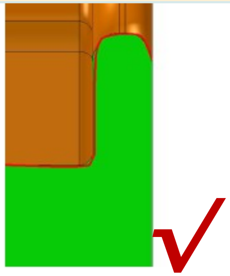
Tolerances & problems

Alex… …ern.ch

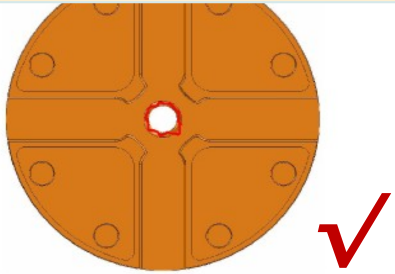
√ *- intensely critical*

Iris shape → ±1µm

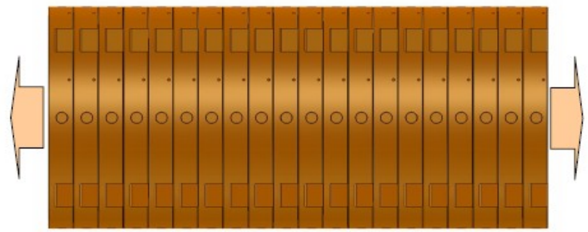
Matching Iris shape → ± 1µm



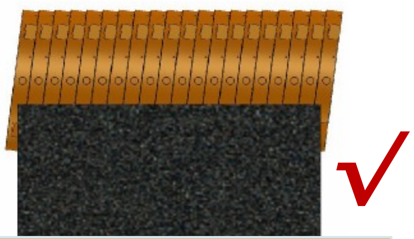
1. Iris shape



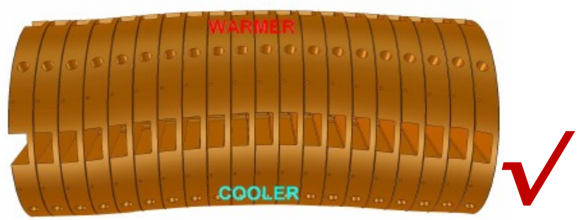
2. Shape of the matching Iris



3. Expansion due to heating

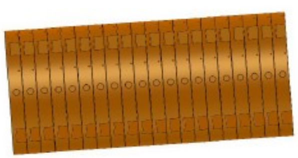


Bookshelf → ± 18 mrad

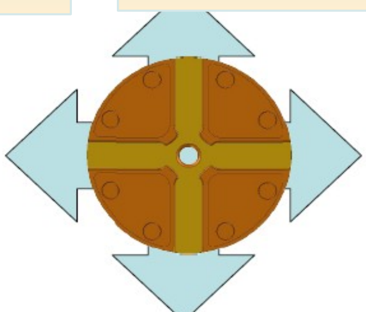


Asymmetric heat dissipation → ± 5 µm

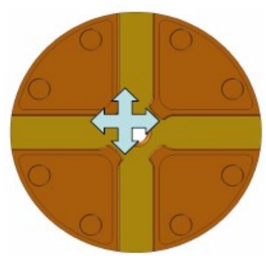
6. Relative position



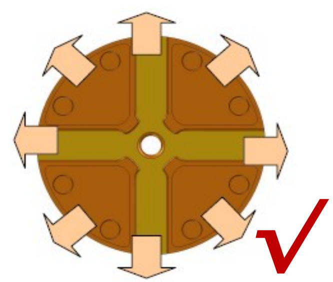
7. Tilt of the structure



8. Deformation of support



9. Support of the structure



10. Isotropic heat expansion

Control of temp. → ± 0,1 °C

Courtesy of R. Zennaro

4 kinds of tolerances:
- Machining (Δx, Δy, Δz)
- Assembly (Δx, Δy, Δz)
- Alignment (Δx, Δy, Δz)
- Operation (ΔT water)

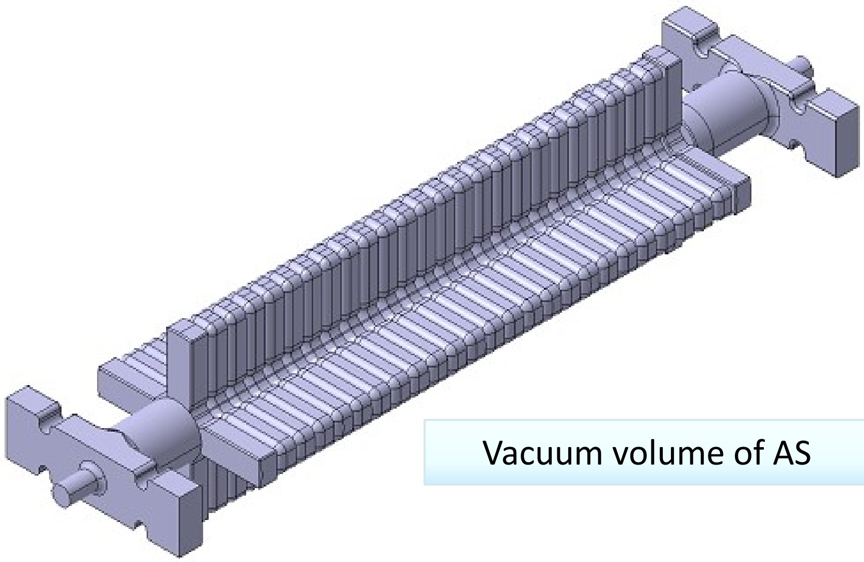
4 types of problems:
- Beam-induced transverse kick (wakefield)
- RF-induced transverse kick
- RF matching (reflected power)
- Phase error

Tolerances study. Summary table.

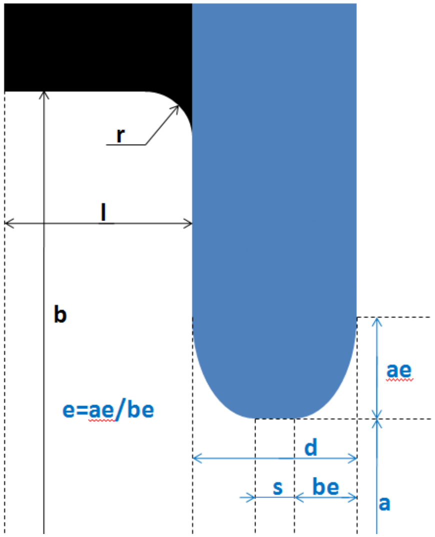
Item	Effect of the item	Performance	Cause				Solution	Magnitude of tolerance	Criticality	Comments	Scheme
			Mach.	Assem.	Align.	Oper.					
SHAPE											
Shape of an Iris	dephasing	lower efficiency	x				Tuning	± 0.001 mm	√ high	local	1
Shape of the matching Iris	mismatching	lower efficiency	x				Tuning	± 0.001 mm	√ high	local	2
LONGITUDINAL											
Expansion due to heat dissipation	dephasing	lower efficiency				x	Thermal elongation compensated (isotropic)	± 0.005 mm	low	thermal elongation	3
Tilt of the disks (Bookshelf)	transverse kick	RF induced transverse kick	x	x			Vertical V-block assembly	± 18 mrad **	√ high	bookshelf	4
TRANSVERSE											
Relative position of disks	wakefield	beam induced transverse kick	x	x			V-block assembly	± 0.005 mm **	low	alignment problem	6
Peak of magnetic field on surface	magnetic field *	local temperature rising	x	x			***	***	low	local	
Expansion due to unsymmetrical heat dissipation	wakefield	beam induced transverse kick				x	Symmetric deformation design	± 0.005 mm	√ high	bending	5
Thermal isotropic expansion	dephasing	lower efficiency				x	Very accurate water temperature control	± 0.1 ° C	√ high	variation of the structures	10
Supporting of accelerating structure	wakefield	beam induced transverse kick	x	x	x		Accurate reference interfaces in structures	± 0.005 mm	low	structure axis w rto beam axis	9
TILT											
Tilt of the full structure	transverse kick	RF induced transverse kick			x		Reference points in the structures	± 0.03 mrad	low	tilt of full structure	7
Deformation of support	transverse kick	RF induced transverse kick				x	Active cooling system	± 0.03 mrad	low	support interference	8

Courtesy of R. Zennaro

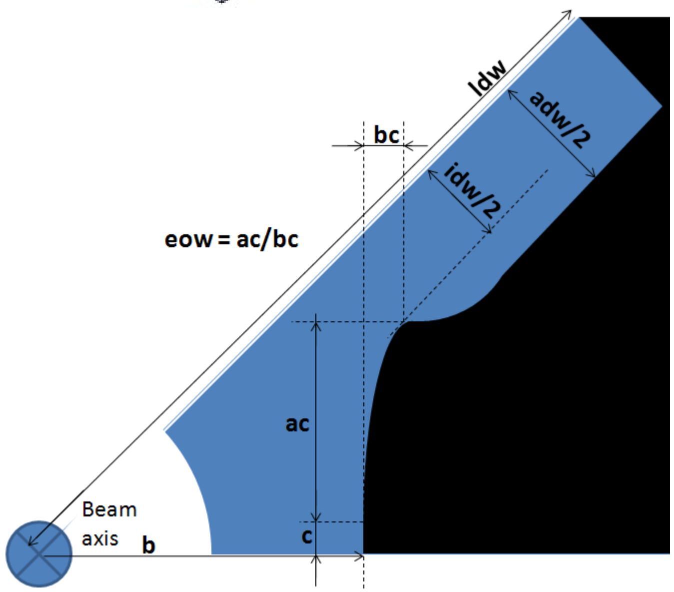
Alex… …ern.ch



Vacuum volume of AS



Iris shape description

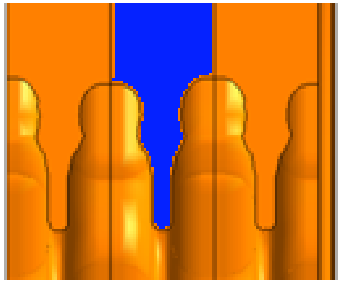
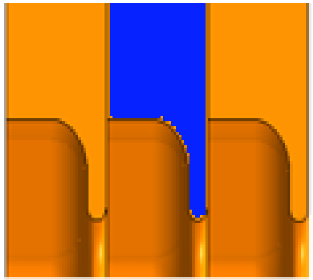
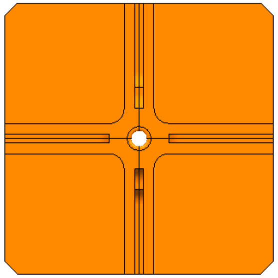
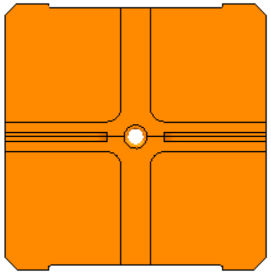
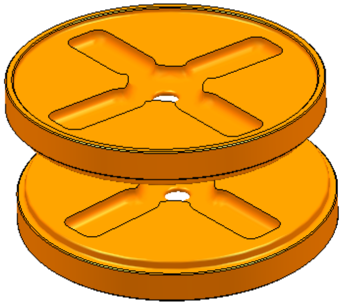
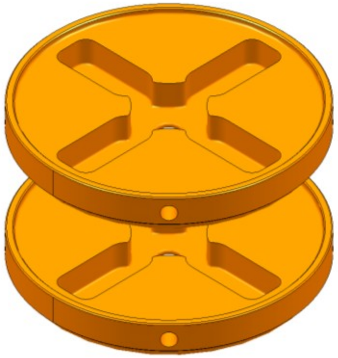
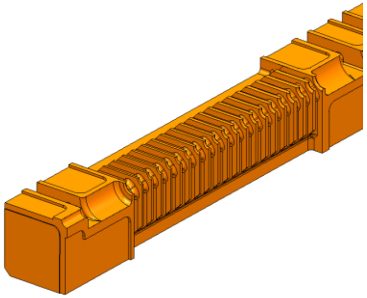
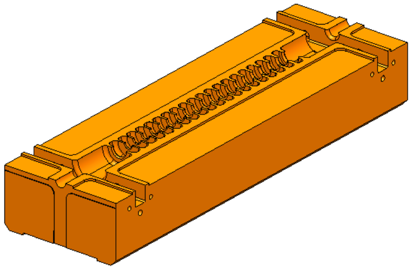


Iris parameters		
Iris #	a [mm]	d [mm]
1	3.15	1.67
2	3.1192	1.6442
3	3.0885	1.6185
4	3.0577	1.5927
5	3.0269	1.5669
6	2.9962	1.5412
7	2.9654	1.5154
8	2.9346	1.4896
9	2.9038	1.4638
10	2.8731	1.4381

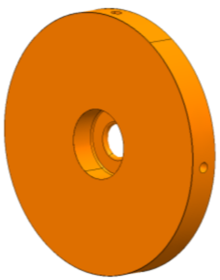
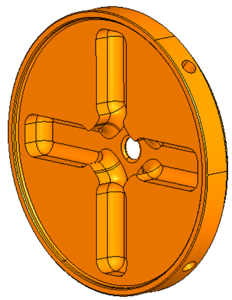
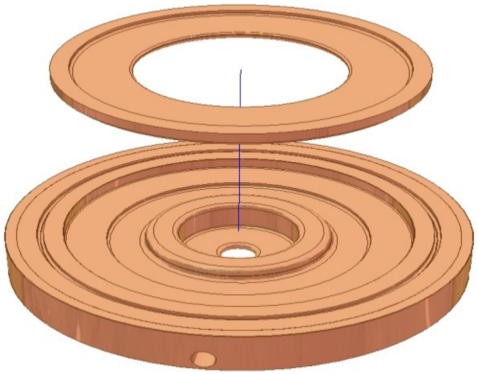
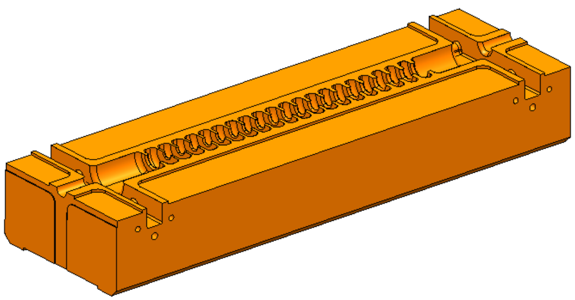
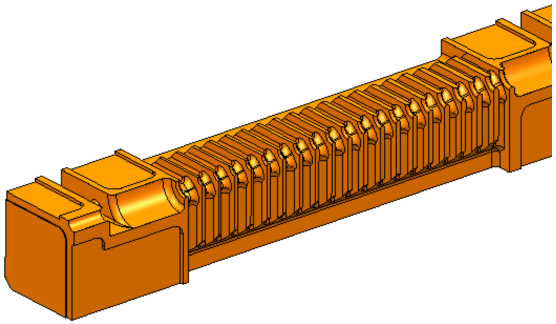
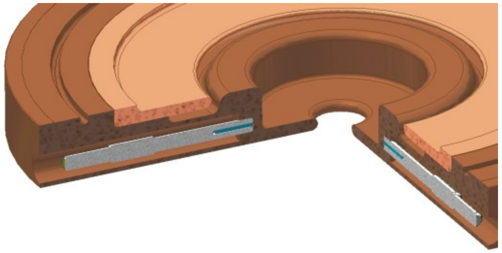
Cell parameters0.5				
Cell #	b [mm]	c [mm]	l [mm]	eow
0		0.65	6.66	3.4
1	8.6154	0.6269	6.6749	3.3962
2	8.6035	0.6208	6.7007	3.3885
3	8.5917	0.6146	6.7264	3.3808
4	8.5801	0.6085	6.7522	3.3731
5	8.5687	0.6023	6.778	3.3654
6	8.5575	0.5962	6.8037	3.3577
7	8.5465	0.59	6.8295	3.35
8	8.5357	0.5838	6.8553	3.3423
9	8.5251	0.5777	6.881	3.3346

Other parameters:
r_pipe = 4 mm
rr_pipe = 1mm
l_pipe > 10 mm
N = 26 – regular cell number
h = 8.332 mm - period
r = 0.5 mm
s = 0.1 *d
e = 1+(d/h)/(a/2.625mm)
idw = 8 mm
adw = 11 mm
ldw = 40 mm

Alex ern.ch

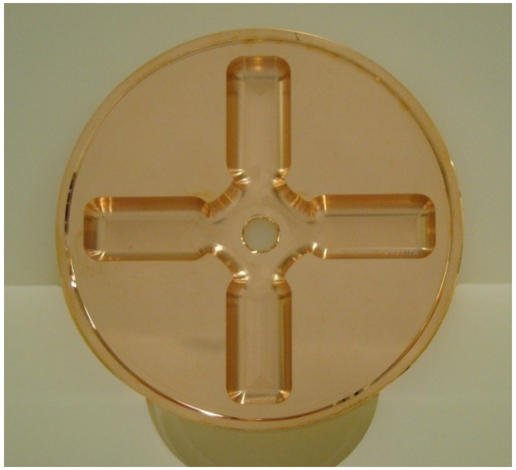
DISK (BASELINE)		**BAR**	
SYMMETRIC	**ASYMMETRIC**	**QUADRANTS**	**HALVES**
			
			

Alex… …ern.ch

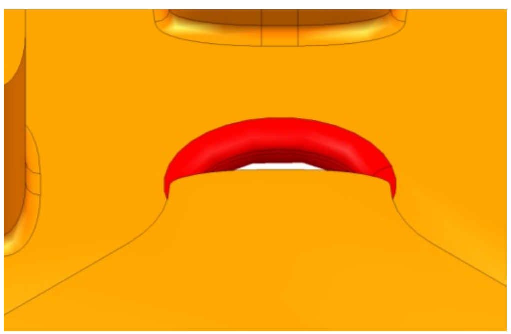
UNDAMPED	WG DAMPING	RADIAL CHOKE DAMPING
 DISK	 DISK	
 HALF (QUADRANT)	 QUADRANT (HALF)	

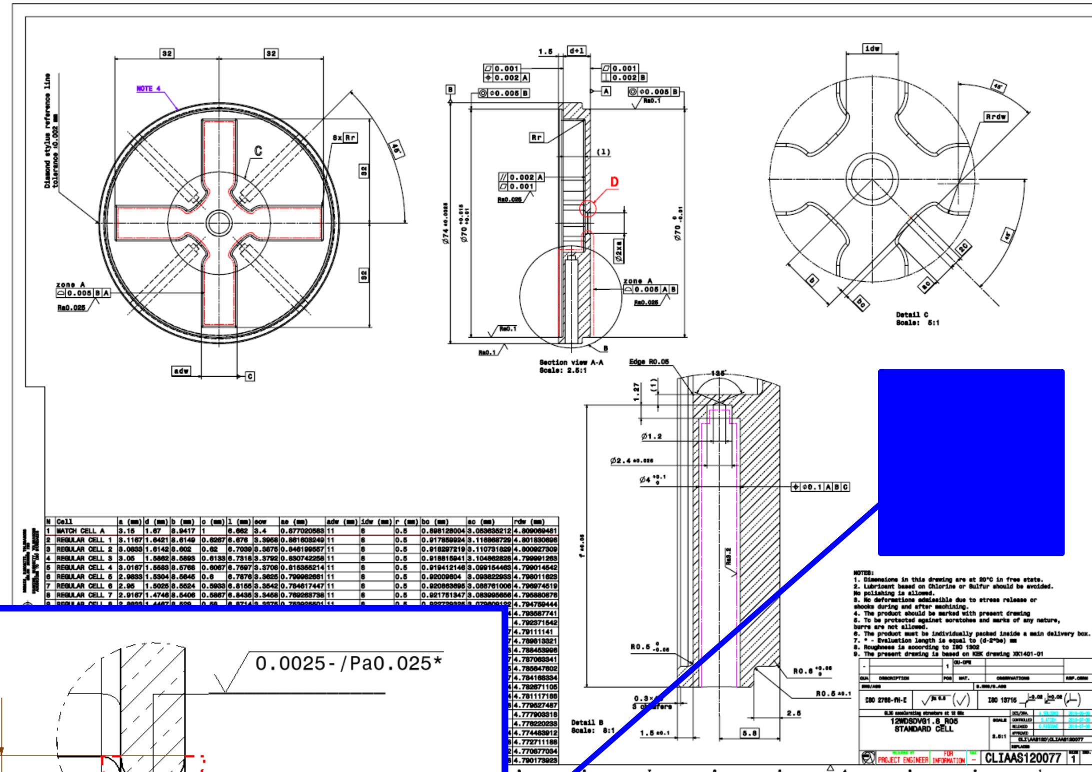
AS cell

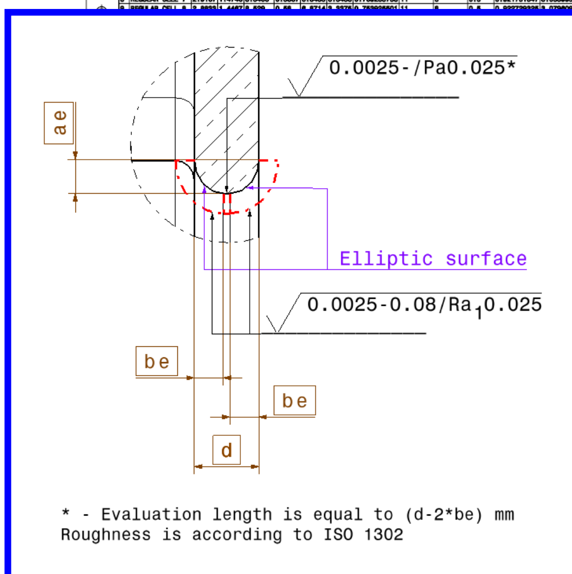
Alex… …ern.ch



AS cell iris – the most critical area





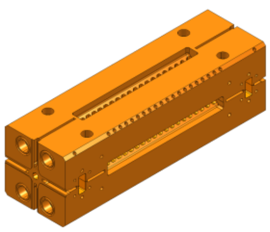
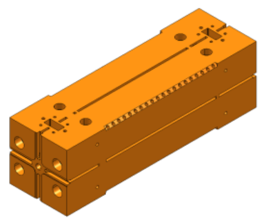
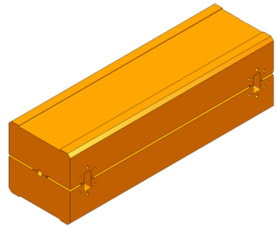
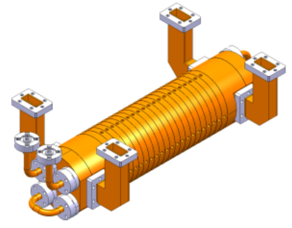
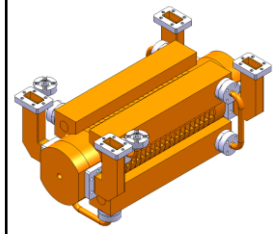
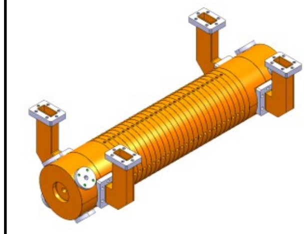
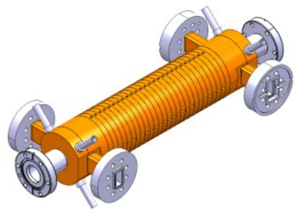
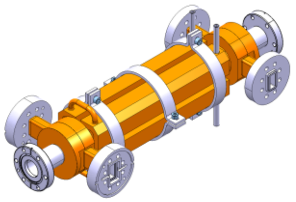
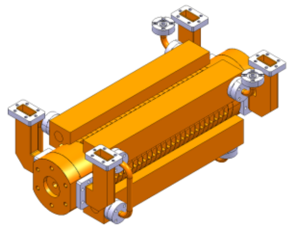
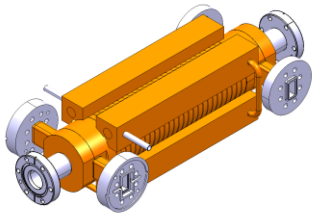
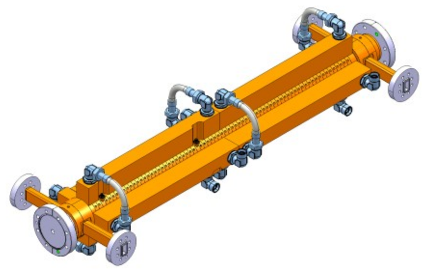
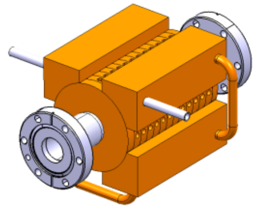
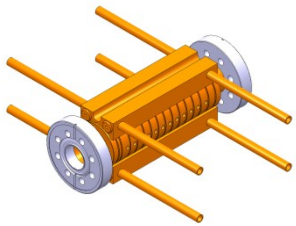
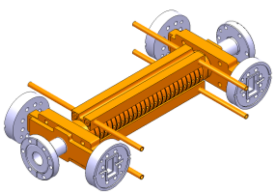
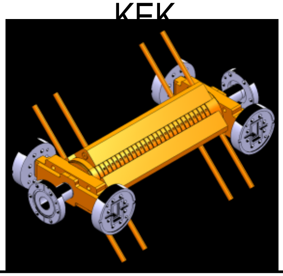
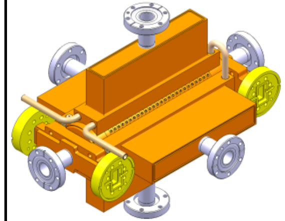
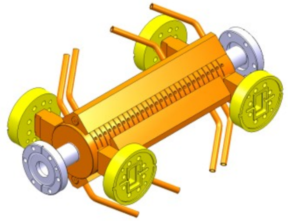


⌓	0.005	A	B
//	0.002	A	
▱	0.001	Ra0.025	

Required geometrical tolerances & surface quality

Test structures

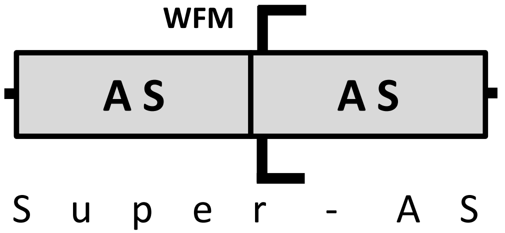
Alex ern.ch

11WDSQVG1 	11WNSQVG1 	TESTS – HALVES 	11WNSDVG1 	11WDSDVG1 	11(12)WNSDVG1.8T 
11(12)WNSDVG1.8S 	11WNSDVG1.8S45 	11(12)WDSDVG1.8T 	11(12)WDSDVG1.8S 	CLIAPSI 	
11CDSD1.4 	11CNSD1.4 	11(12)WNSDVG1.8 KEK 	11(12)WDSDVG1.8 KEK 	12WDSDVG1.8 R05_SiC 	12WDSDVG1.8R05 _CC 

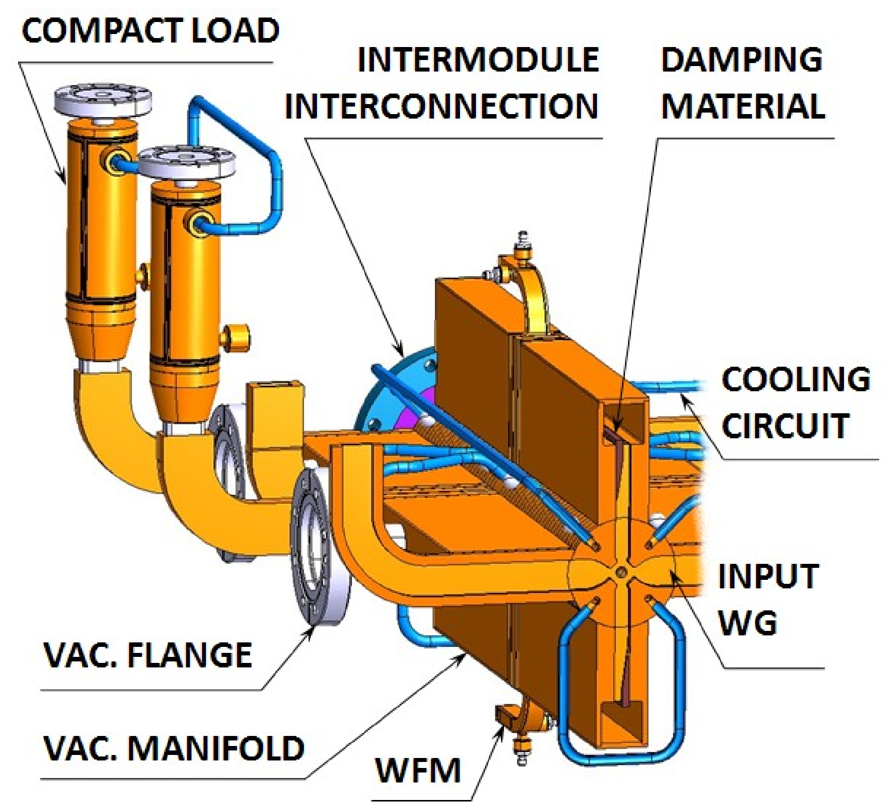
Different mechanical design approaches

Alex… …ern.ch

The design of AS is driven by extreme performance requirements. The assembly accuracy is ±5 μm. Many features of different systems, such as vacuum, cooling, WFM as well as damping waveguide absorbers are incorporated into design.



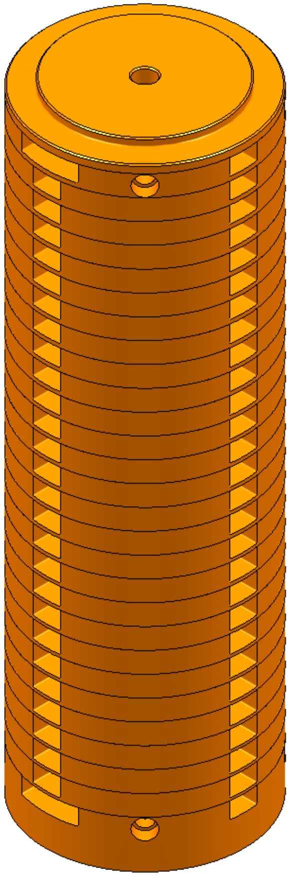
Schematic layout of CLIC Module Super-AS



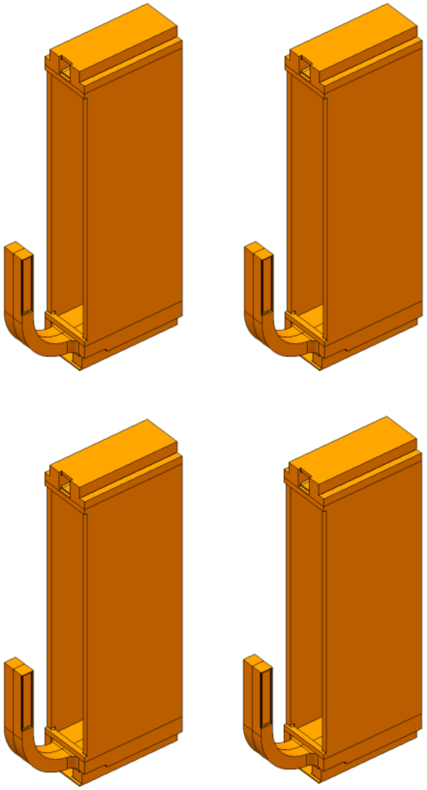
COMPLEXITY

Brazed disks with “compact” coupler & vacuum system, micro-precision assembly, cooling circuits (~400 W per AS), wakefield monitor (1 WFM per SAS), interconnection to MB Q (stabilization!), structure support (alignment), output WG with RF components (e.g. loads), RF distribution (WGs & splitters)

Assembly of AS (1/3)

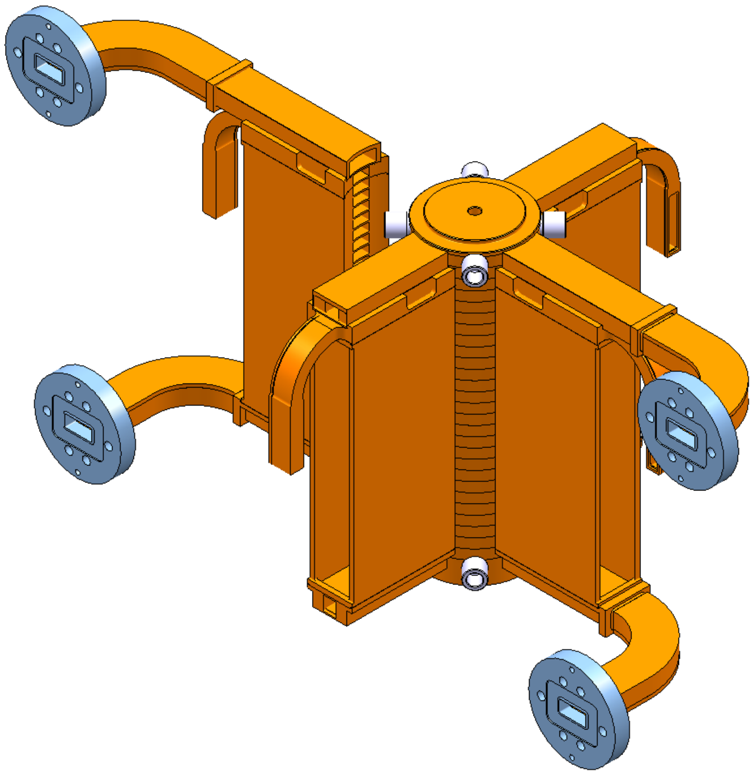


1. Diffusion bonding of high precision disk stack

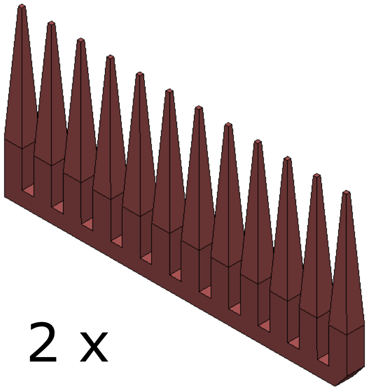


2. Brazing of manifolds

3. Brazing of AS and vacuum manifolds together



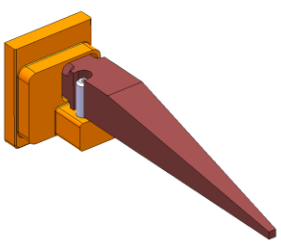
Alex… …ern.ch



2 x

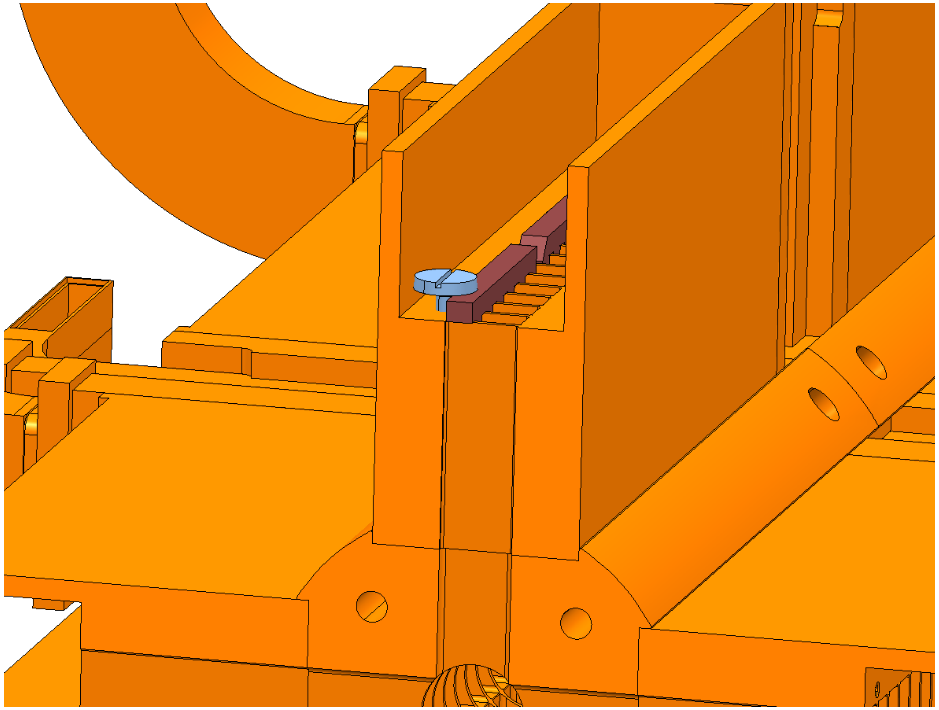
per manifold

SiC absorbers



1 x

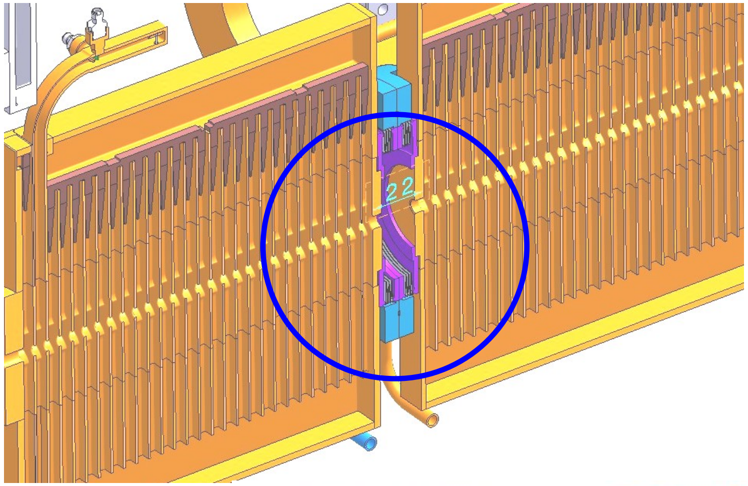
per WFM



Damping material installation

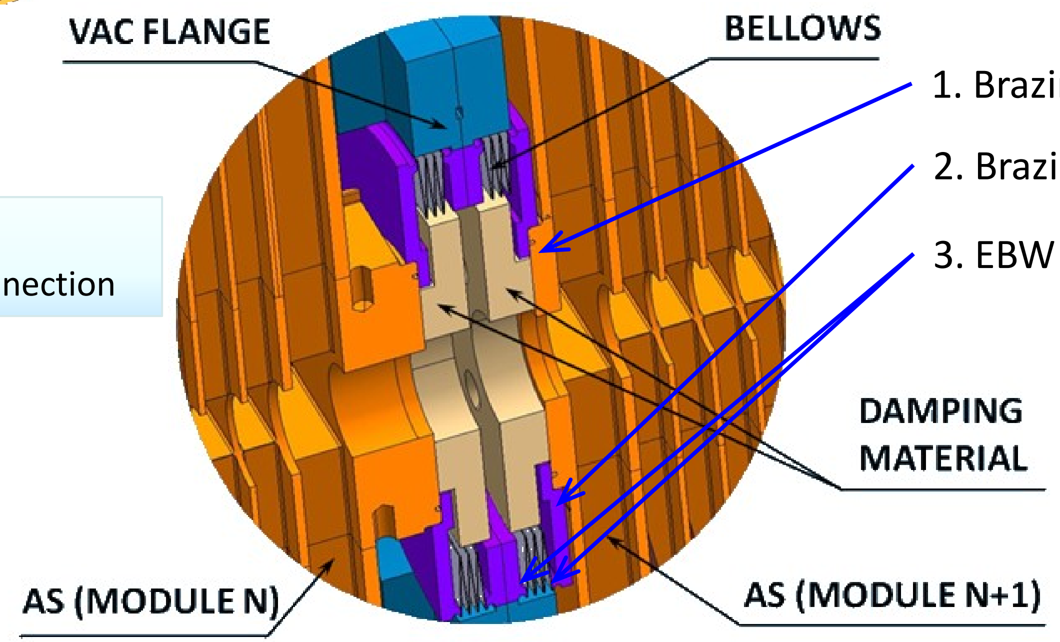
Assembly of AS (3/3)

Alex ern.ch



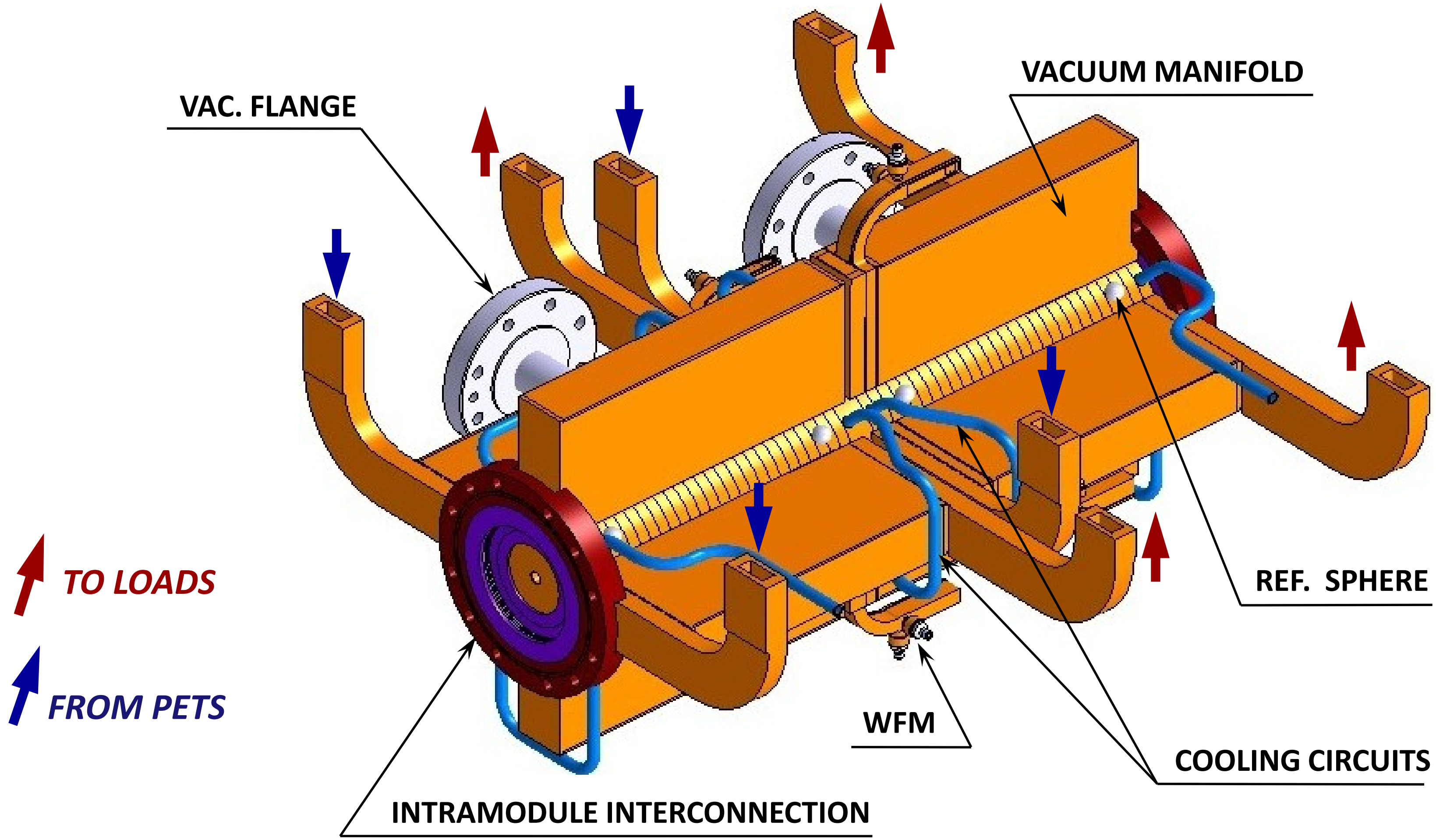
A low pressure level (10^{-9} mbar) is needed for keeping the good beam quality. The interconnections between main components should sustain the vacuum forces, provide an adequate electrical continuity with low impedance and remain flexible not to restrict the alignment.

Intermodule AS
vacuum interconnection



1. Brazing of the AS end piece
2. Brazing of special StSt piece
3. EBW of bellows and vacuum flange

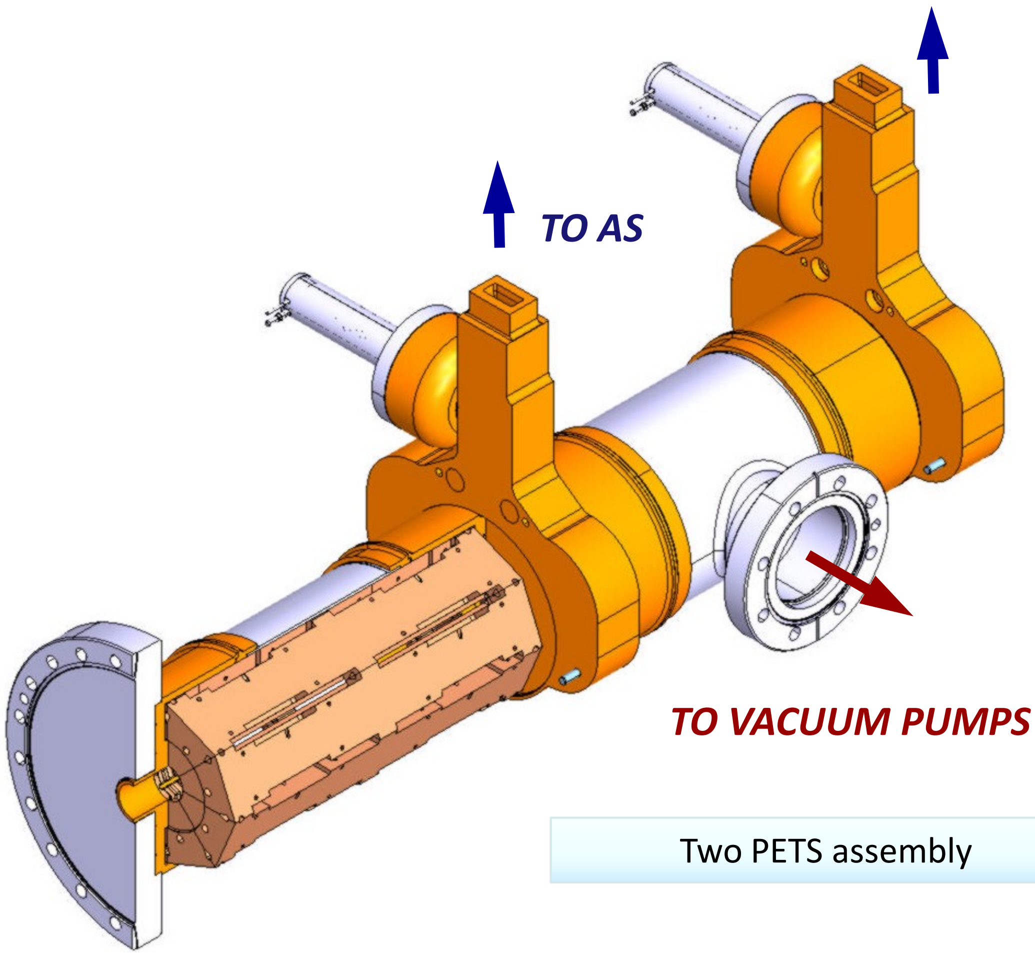
Alex… …ern.ch



Two AS (~250 mm) form one Super-AS (~500 mm)

Alex… …ern.ch

CLIC PETS is one of the key components in the CLIC two-beam acceleration scheme. It is a passive microwave device, in which bunches of the DB interact with the impedance of the periodically loaded waveguide and generate RF power for the AS (MB).

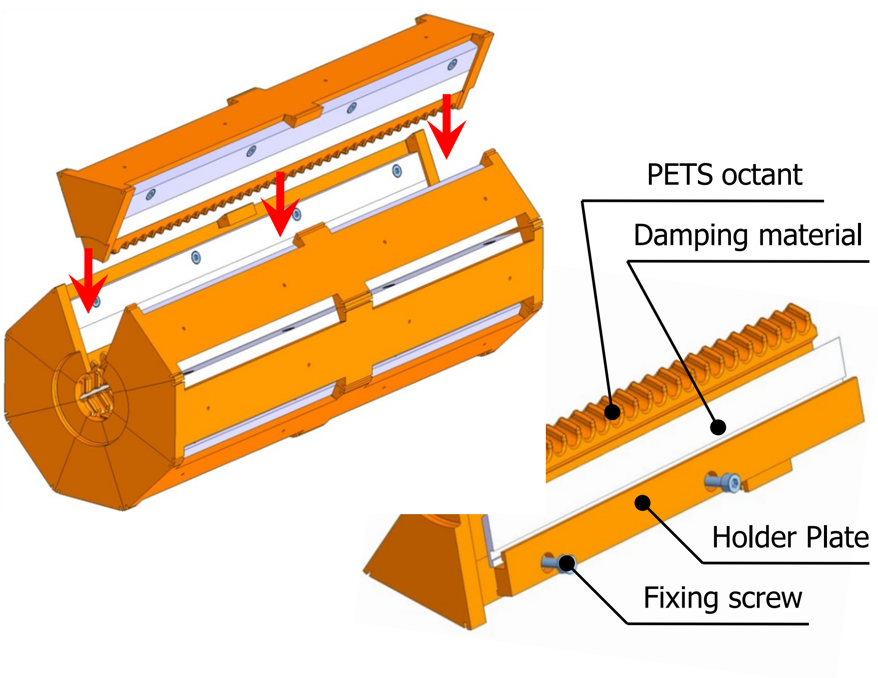


Two PETS assembly

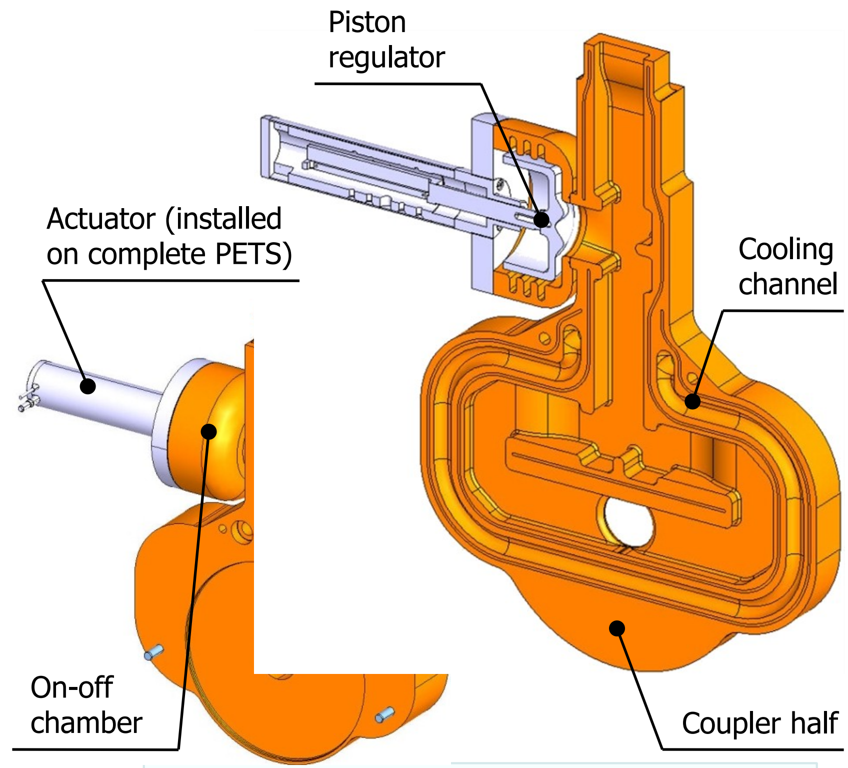
Alex ern.ch

PETS body is composed of eight identical parts, octants. The copper octant has a wedge-shaped cross-section profile, while the narrow side of octant has the corrugated RF geometry. Each octant is damped with SiC shim attached to the lateral surfaces.

The compact coupler combines three functions: transferring RF power to the AS, connecting two PETS and cutting the produced power by means of integrated "On-Off" mechanism, which momentary (<20ms) changes the geometry of the waveguide.

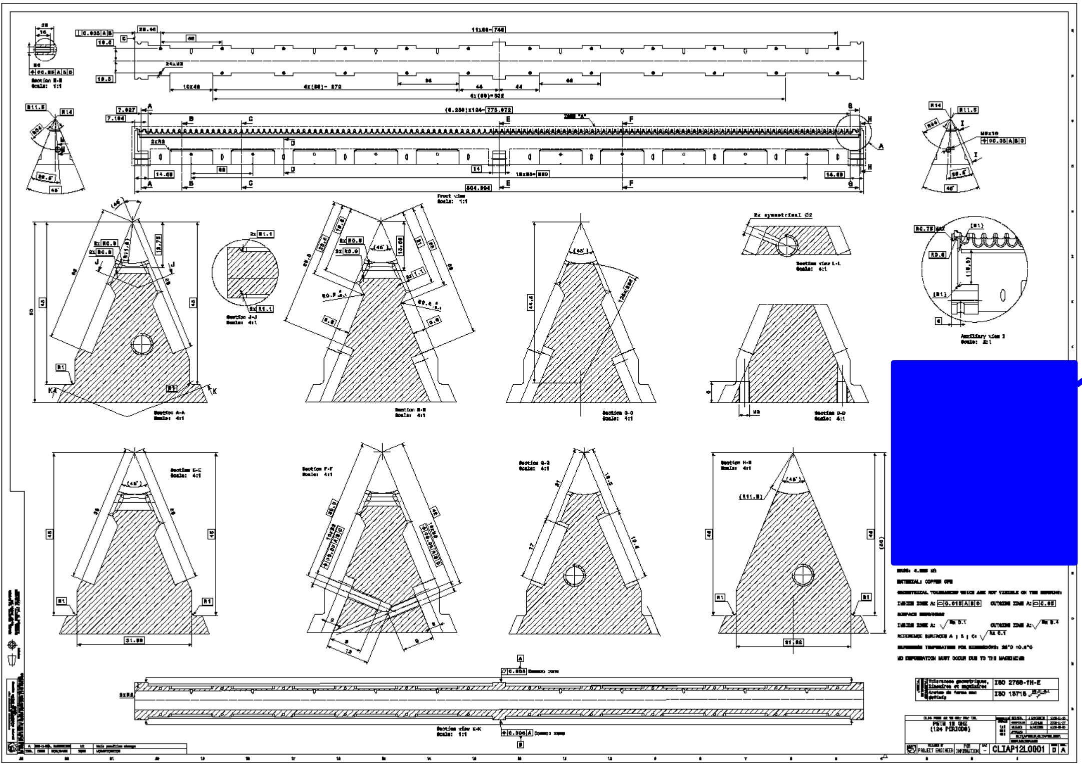


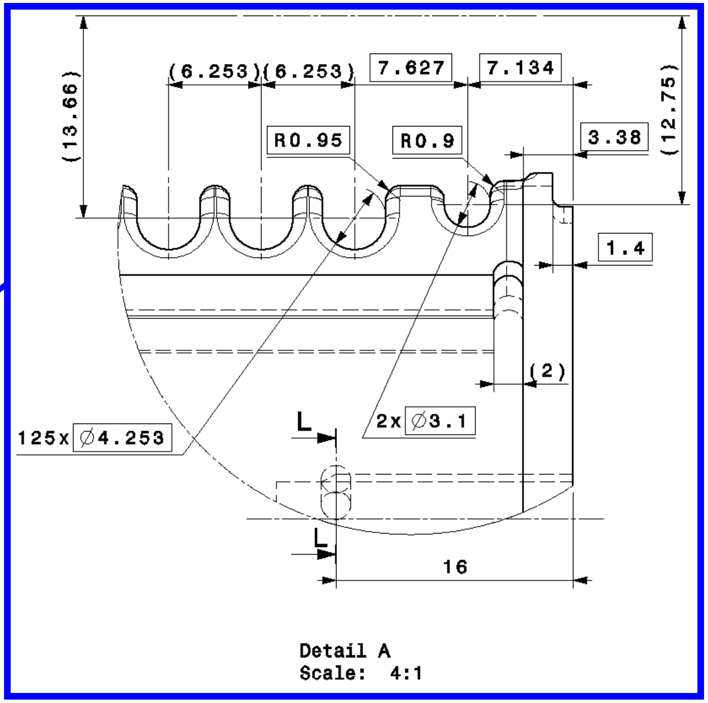
PETS body

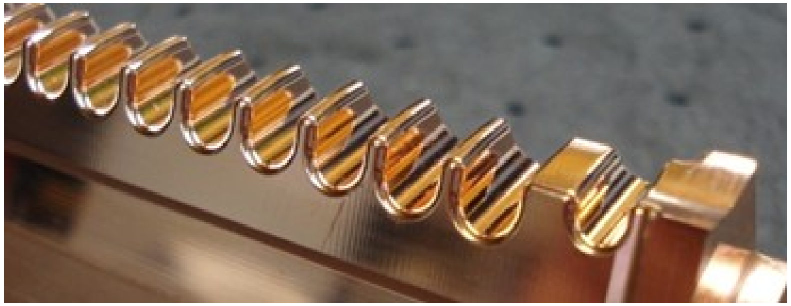


Compact coupler with On-Off mechanism

Alex… …ern.ch



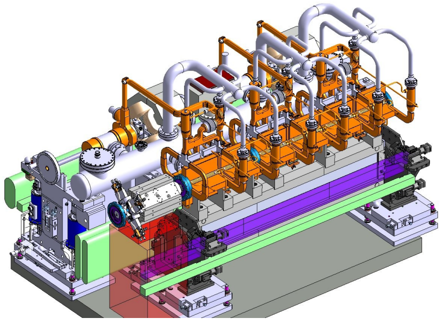




Shape accuracy 15 µm

Roughness Ra 100 nm

Alex… …ern.ch



Mechanical design must take into account all requirements of beam physics , RF design, production and assembly methods, as well as installation and operation.

Stringent tolerances imply the precise and ultra-precise machining procedures, including also special pre- and intermediate heat treatments.

CLIC structures combine many features of different technical systems, so lots of additional engineering issues have to be solved.

Industrialization studies are going in parallel in collaboration with manufacturers and modifications expected to be implemented "on fly".

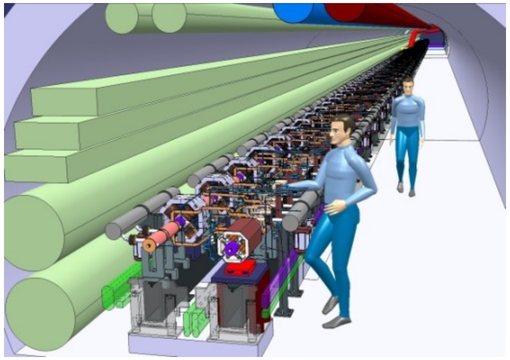
Specific requirements for packaging, transport and for the control procedures

CLIC at 3 TeV (20924 modules) would require:

→142812 Accelerating structures;

→ 71406 PETS, and

→ about 400000 RF components



Questions, discussion

Alex… …ern.ch

?

?

?

Acknowledgement

Many thanks
to all mechanical designers
and CLIC Module
Working Group members !

THANKS

FOR

YOUR

ATTENTION

& INTEREST !

Backup

Due to the very large amount of structures the implementation of tuning in the final design is not suitable, for this reasons the tolerances are defined on the assumption to avoid any possible tuning. A detailed study of the required machining and assembly tolerances has been performed [8] which is summarized below.

•Systematic errors: Inefficiency in acceleration due to rf de-phasing is mainly caused by systematic errors in the cell dimensions since it is a coherent effect. The most sensitive dimension is the transverse size of the cell 2b where 1 micrometer systematic error causes ~2% reduction in the structure acceleration.

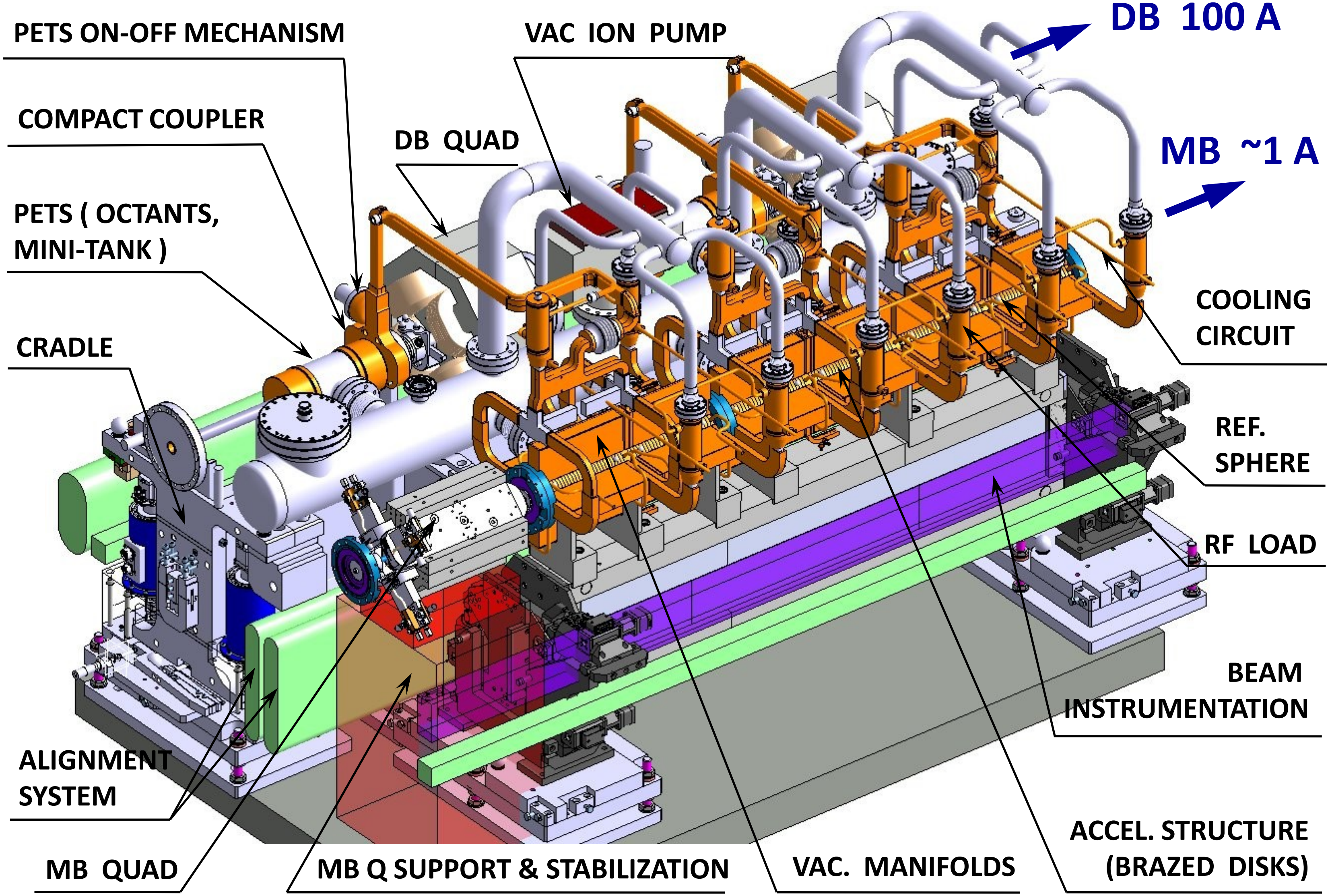
•Random errors: Cell to cell frequency error due to random errors in cell dimensions causes mismatch, reflections and appearance of field enhancement due standing wave. Limiting the mismatch to < -40dB results in the same tolerance on the most critical dimension 2b of ~1 micrometer.

•"Bookshelfing": Systematic tilt of the disks introduces the transverse kick which is proportional to the accelerating gradient. Keeping ratio of the transverse kick to the acceleration dVt/dVz <10e-4 (see, BD section) requires the tilt to be below 180 micro-radian.

•WFM: The required WFM accuracy must be below 3.5 micrometers. This sets the limit on the cell shape accuracy such that the transverse alignment of the axis of the iris aperture (source of the short range wakes) with respect to the axis of the cell and damping waveguides (measuring the wakes) must be at least better than 3.5 micrometers.

In summary, micrometer tolerance level is required in cell disk fabrication and several micrometers in the structure assembly in order to satisfy stringent beam dynamics requirements without additional tuning.

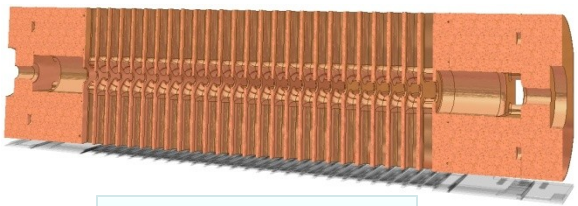
CLIC Module Type1



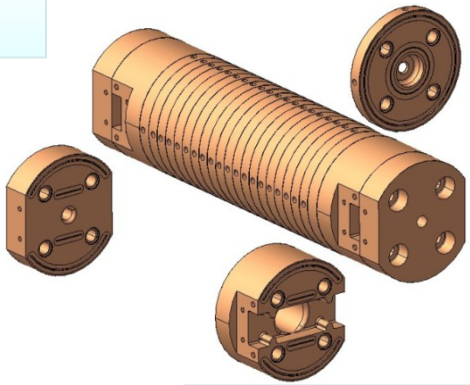
AS in disks and quadrants

Alex… …ern.ch

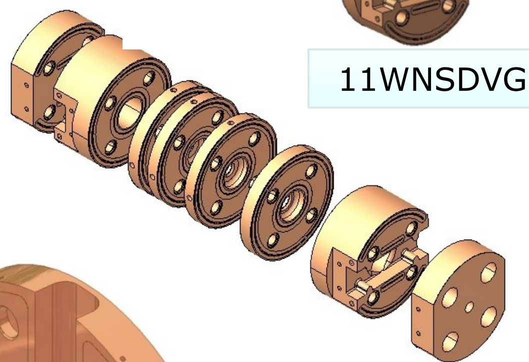
DISK

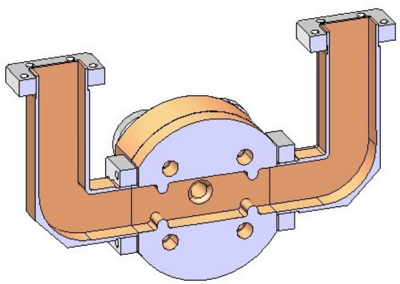


11WDSDVG1.8T

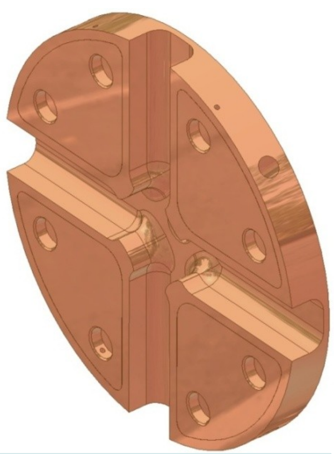


11WNSDVG1.8T



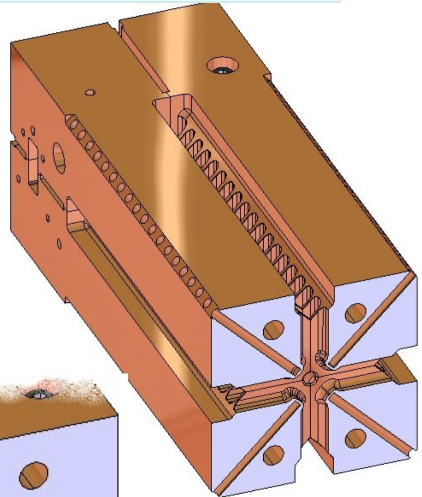


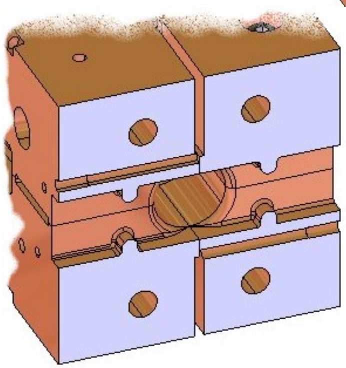
Coupler & WG
(assembly cut)



12GHz AS disk
(damped version)

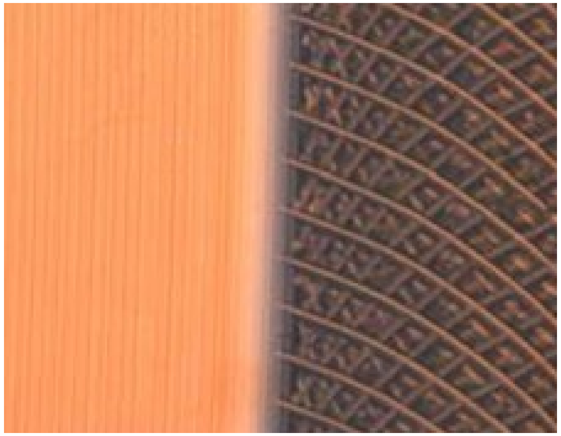
QUADRANT



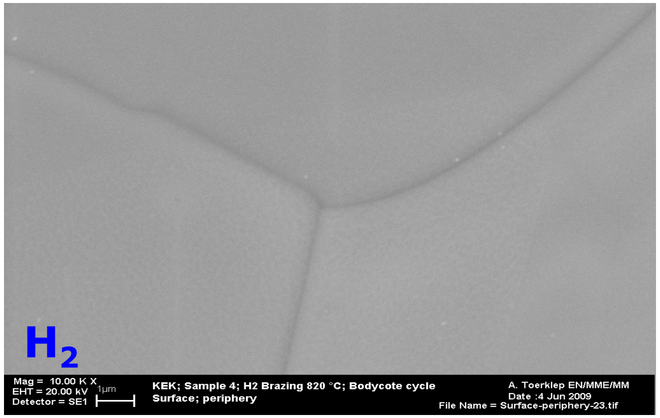


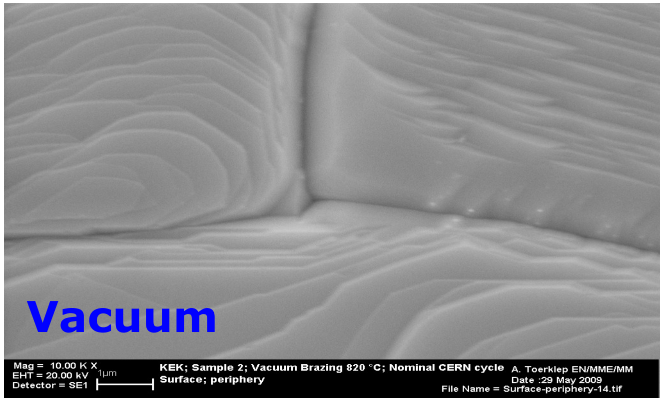
11 GHz
AS in quadrant

Irises (on 1 quadrant)



Turning vs. milling





Diffusion bonding

(vacuum vs. hydrogen environment)