Structure fabrication and assembly tolerances

R. Zennaro

Tolerances of the structures

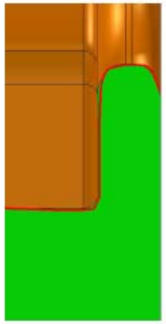
4 kinds of tolerances:

- *Machining (Δx, Δy, Δz)*
- *Assembly (Δx, Δy, Δz)*
- *Alignment (Δx, Δy, Δz)*
- *Operation [Cooling] (ΔT (t) water in, ΔT (z))*

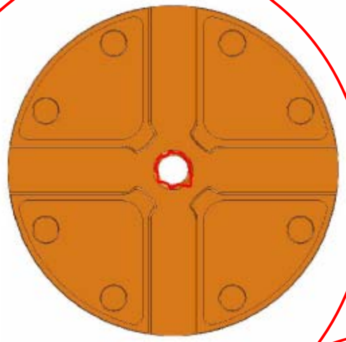
4 kinds of problems:

- *Beam induced transverse kick (wakefield)*
- *RF induced transverse kick*
- *RF matching (reflected power)*
- *Phase error*

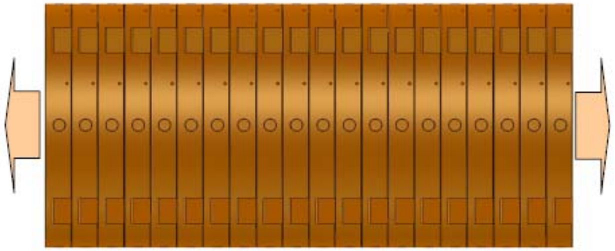
Item	Effect of the item	Performance	Cause				Solution	Magnitude of tolerance	Criticality	Comments	Scheme
			Mach.	Assem.	Align.	Oper.					
SHAPE											
Shape of an Iris	dephasing	lower efficiency	x				Tuning	± 0.001 mm	high	local	1
Shape of the matching Iris	mismatching	lower efficiency	x				Tuning	± 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.r.to 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



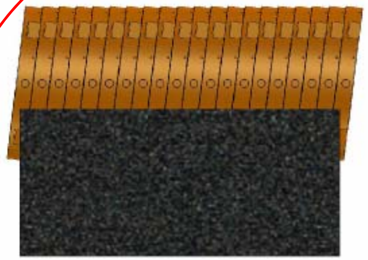
1. Iris shape



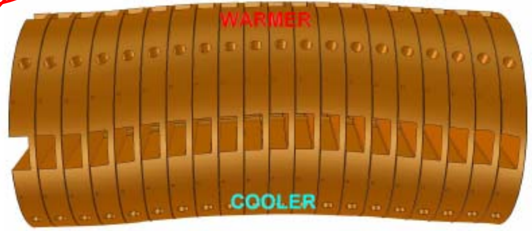
2. Shape of the matching Iris



3. Expansion due to heating

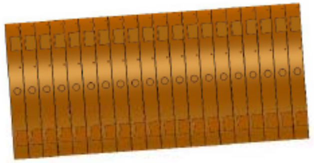


4. Tilt of the disk

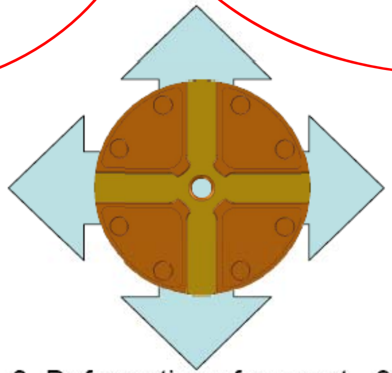


5. Unsymmetrical heating

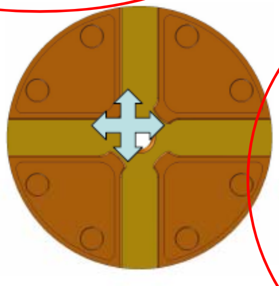
6. Relative position



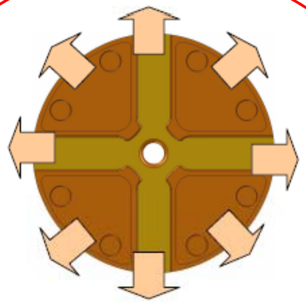
7. Tilt of the structure



8. Deformation of support



9. Support of the structure

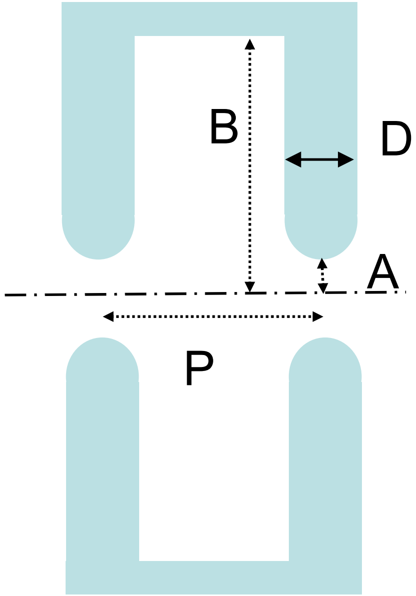


10. Isotropic heat expansion

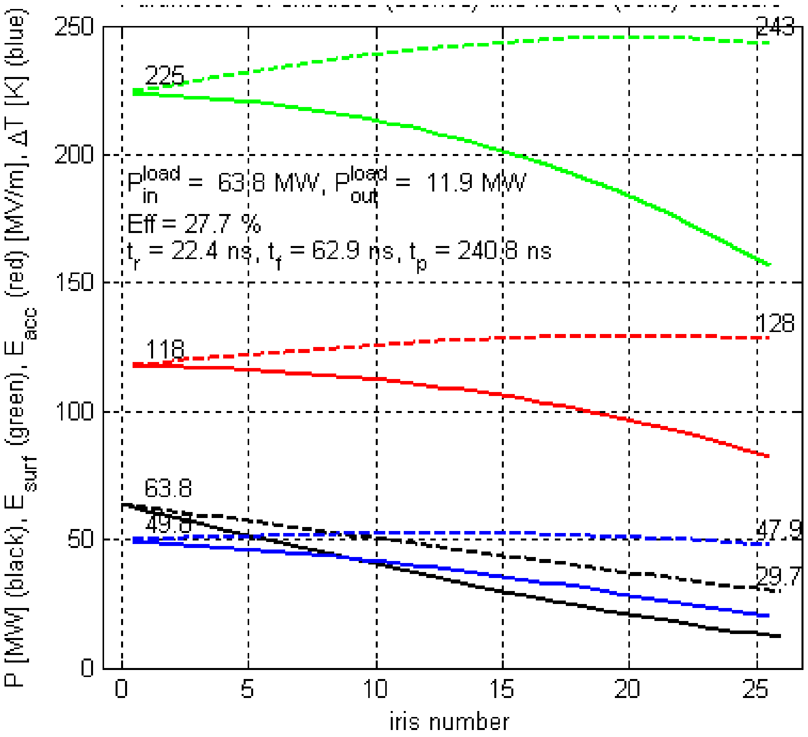
Structure Shape

Dephasing: **Beam dynamics:** An error in the cell shape determines a wrong phase advance

Mismatching: **Reflected power**: in a structure a geometrical error introduces a reflection i.e. lower efficiency. Considering the last cell (narrowband; v_g=0.83%) , the pass band at -30 dB is ~5 MHz and the computed tolerance (ᴅB) to get S11< -30 dB is ~1.5 micron, if any tuning is applied.



The sensitivity of the phase advance to the main geometrical parameters has been computed for the different cells of the CLIC_G structure. Strong dependence on the group velocity: vg/c(%): 1.66 (first cell) 0.83 (last cell)

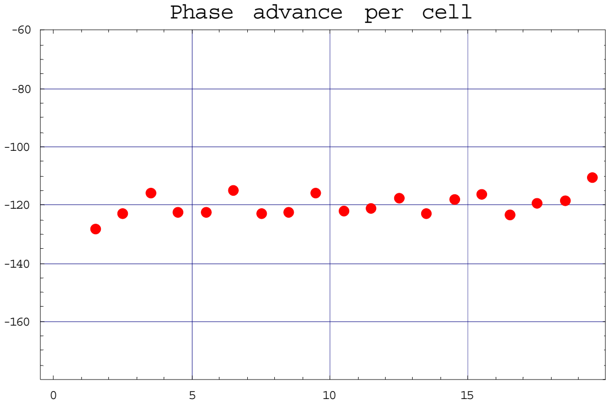


CLIC_G

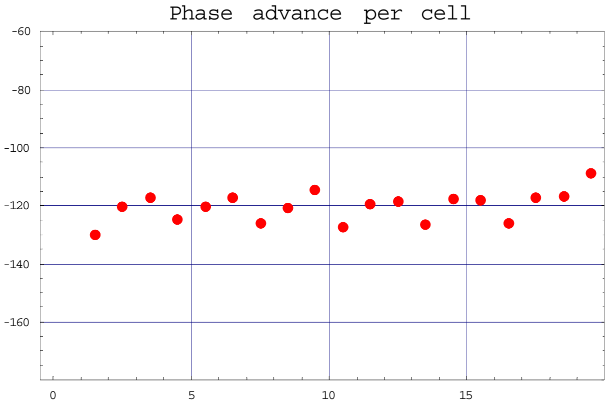
Courtesy of A. Grudiev

Example of errors: CLIC_VG1: RF measurements in KEK

Every error can distribution can be schematically considered as the sum of **systematic errors plus random errors**

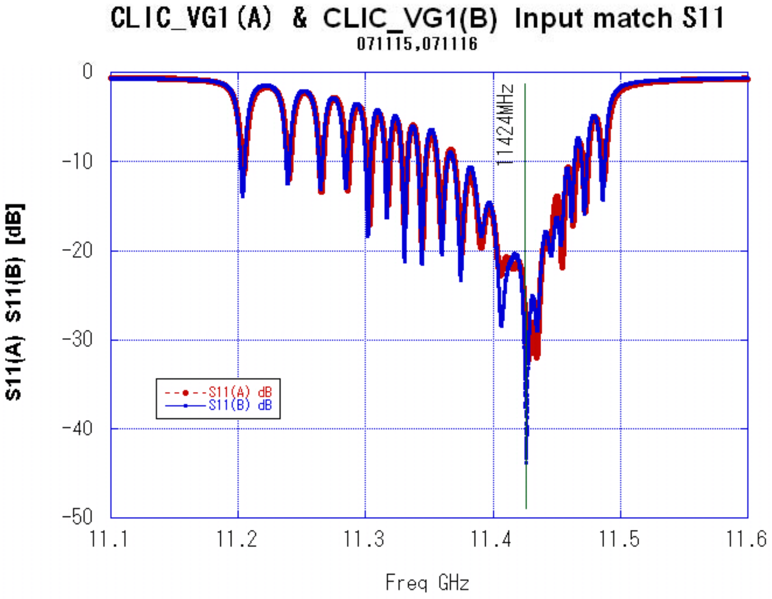


Average phase advance per cell
-119.943 degrees / cell



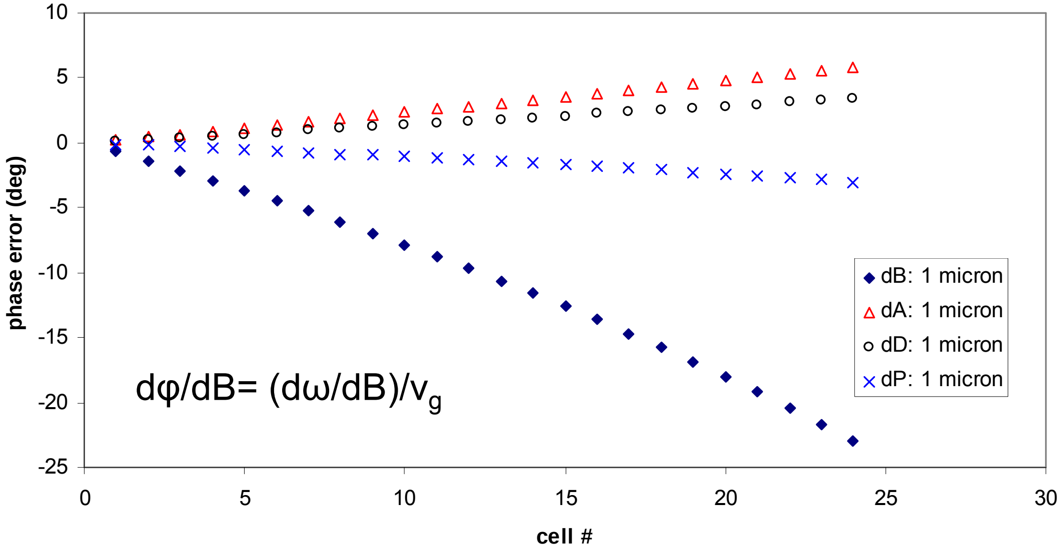
Average phase advance per cell
-120.424 degrees / cell

Single cell phase advance error up to 10 deg,
sigma A~ 4.5 deg, sigma B~ 5.6 deg



Courtesy of T. Higo

Structure Shape (systematic error)

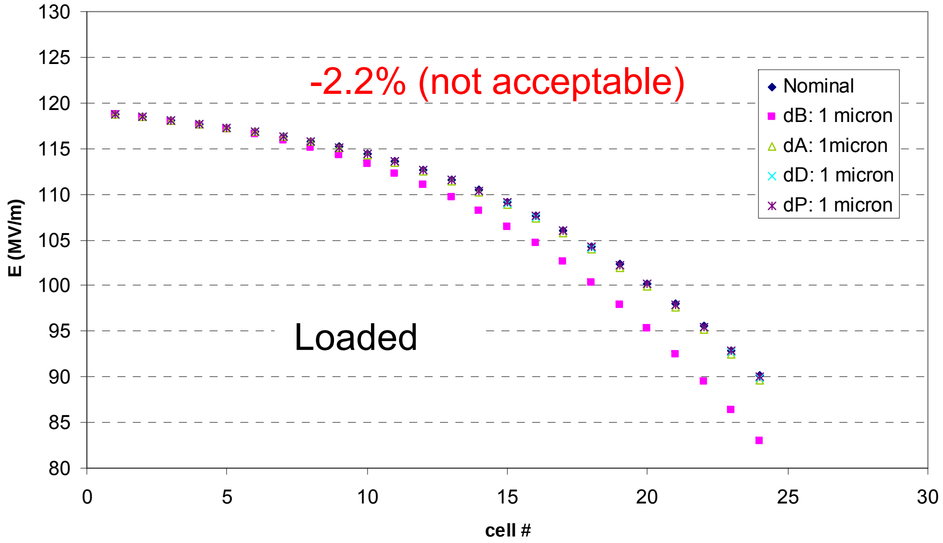


$d\varphi/dB = (d\omega/dB)/v_g$

	df/dB (radius) [MHz/μm]	dph./df [deg/MHz]
cell1	1.1	0.6
cell24	1.0	1.2

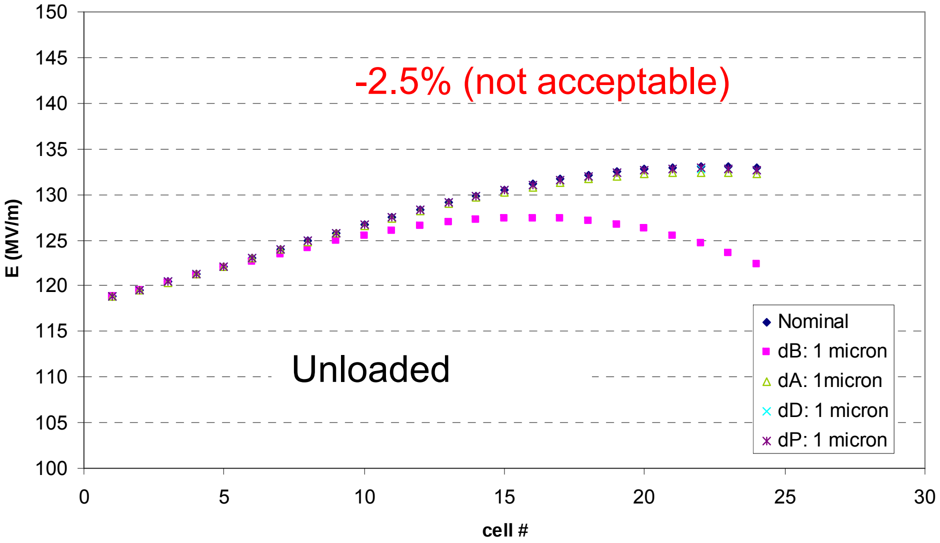
Cumulative error: 1 micron error, if systematic, gives a very large error on the average phase advance per cell (~11 deg cumulative phas. err.)

The phase error implies a variation on the effective accelerating field



-2.2% (not acceptable)

Loaded

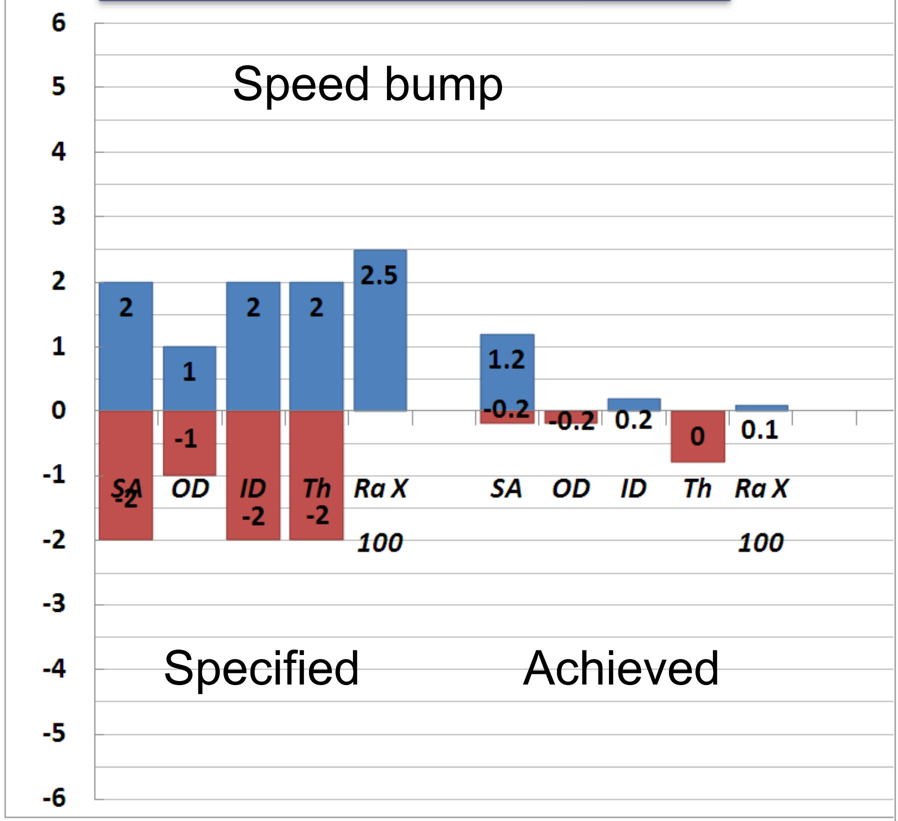


-2.5% (not acceptable)

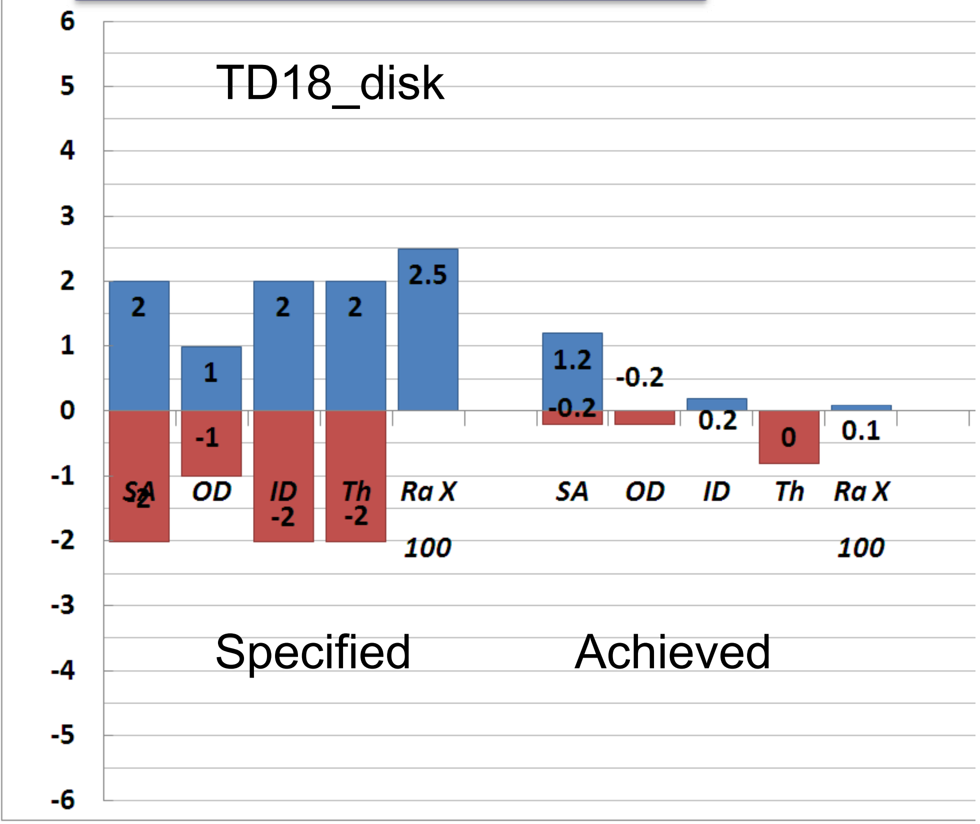
Unloaded

Achieved accuracy (disk)

30 GHz [accuracy in µm]

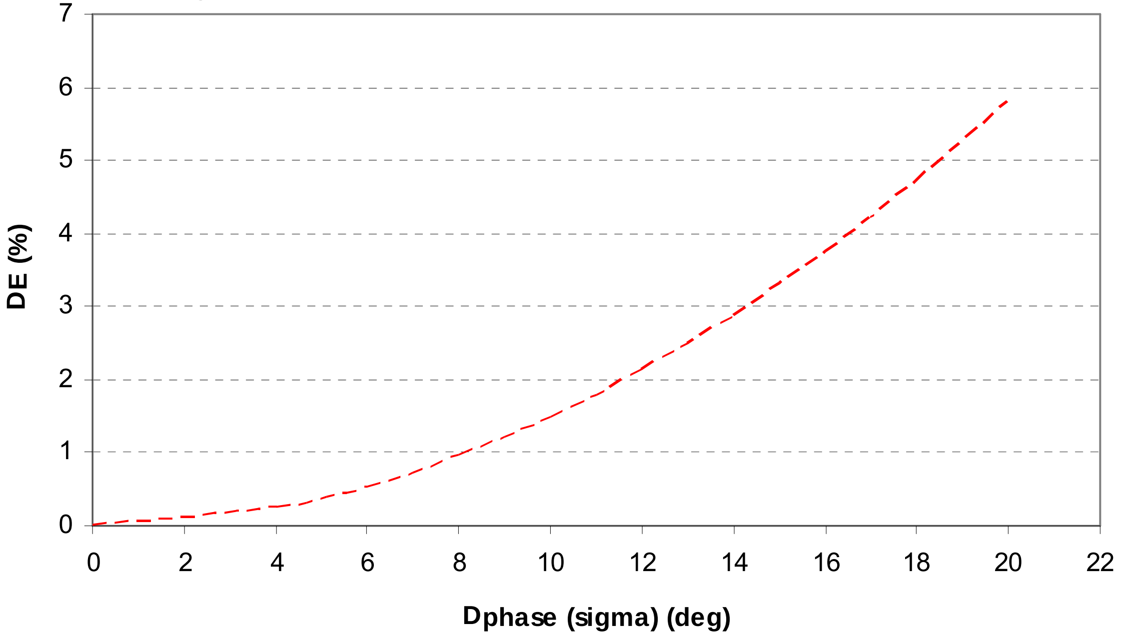


11.4 GHz [accuracy in µm]



SA: iris shape accuracy
OD: outer diameter
ID: inner diameter
Th: iris thickness
Ra: roughness

Structure Shape (random error)

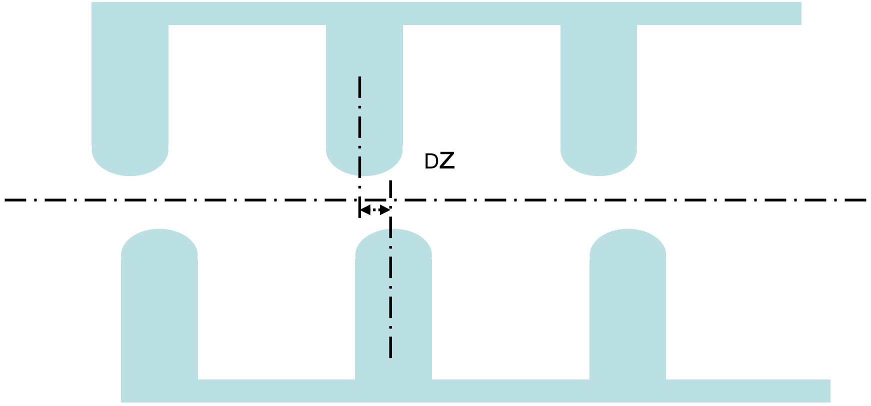

Gradient error generated by a Gaussian distribution of the cumulative phase;
NO average phase error.

Acceptable average gradient error: sigma=2% (D. Schulte)

⬇

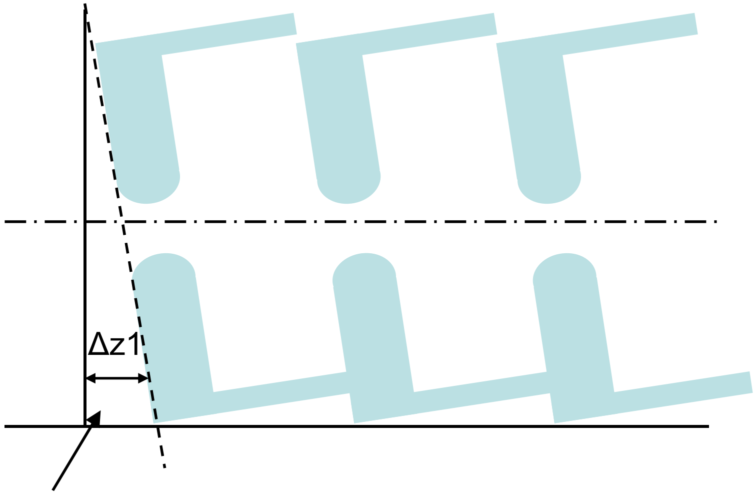
DB <17 microns (first cell); 9 microns (last cell)

Bookshelf or longitudinal misalignment of half-structure



Structure in quadrants

problem mainly for the **machining** and **assembly**

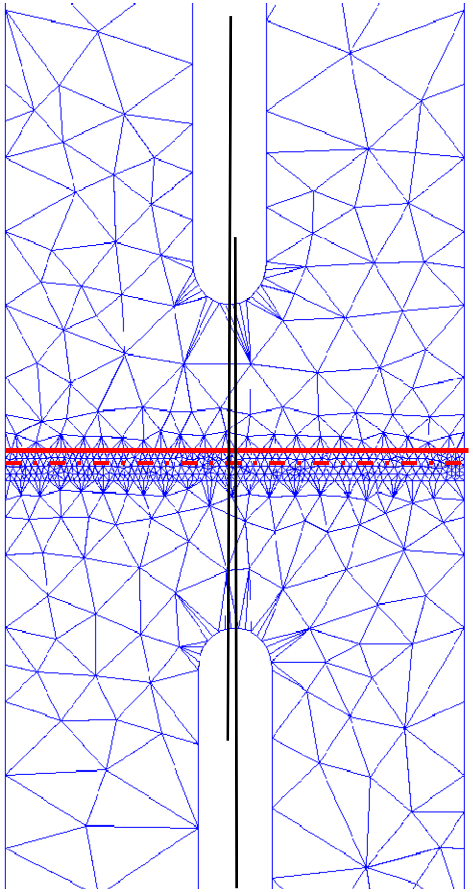


$\Delta z1 \approx D/a^* \, \Delta z$

Structure in disks

problem mainly for the **brazing** **(assembly)**; probably easier to achieve

Bookshelf or longitudinal misalignment of half-structure



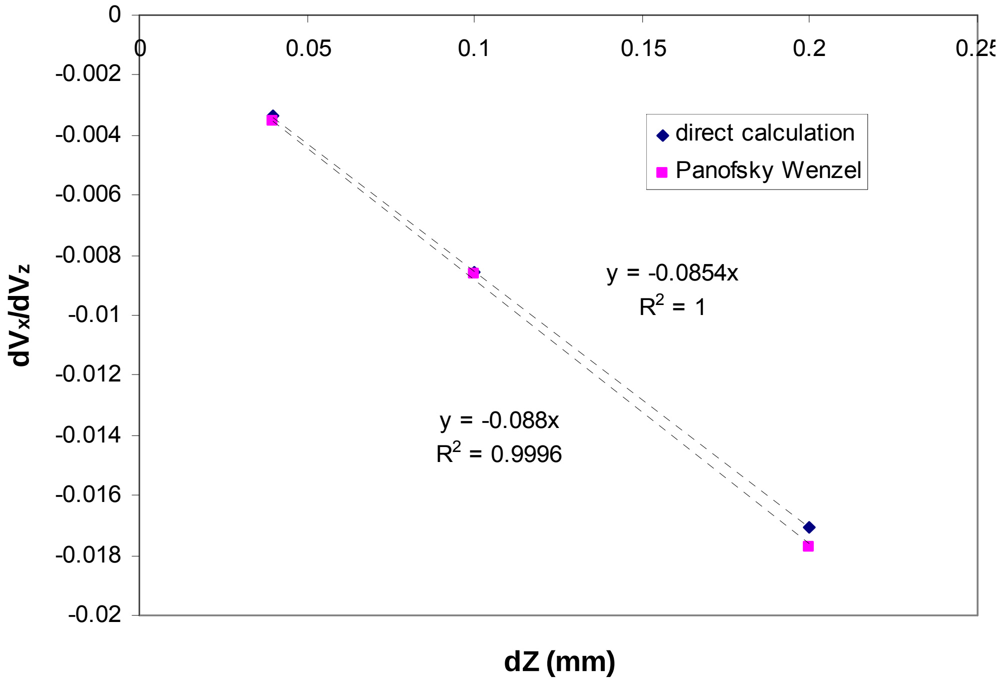
Middle cell of CLIC_G (a=2.75mm)

$$Vx := \int_0^{Zend} \left[(EX(z) - HY(z)) \cdot \exp\left[i \cdot (\kappa \cdot z - \phi) \right] \right] dz$$

Direct kick calculation

$$\Delta \vec{V}_{\perp} = i \frac{v}{\omega} \vec{\nabla}_{\perp} (\Delta V_{II})$$

Panofsky Wenzel (cross-check)



dVx/dVz~0.087*dz computed

dVx/dVz=dz/(4*a)=0.09*dz

Prediction (Daniel)

Equivalent bookshelf angle: α=dz/2a

Tolerances: 1micron or 180 μrad

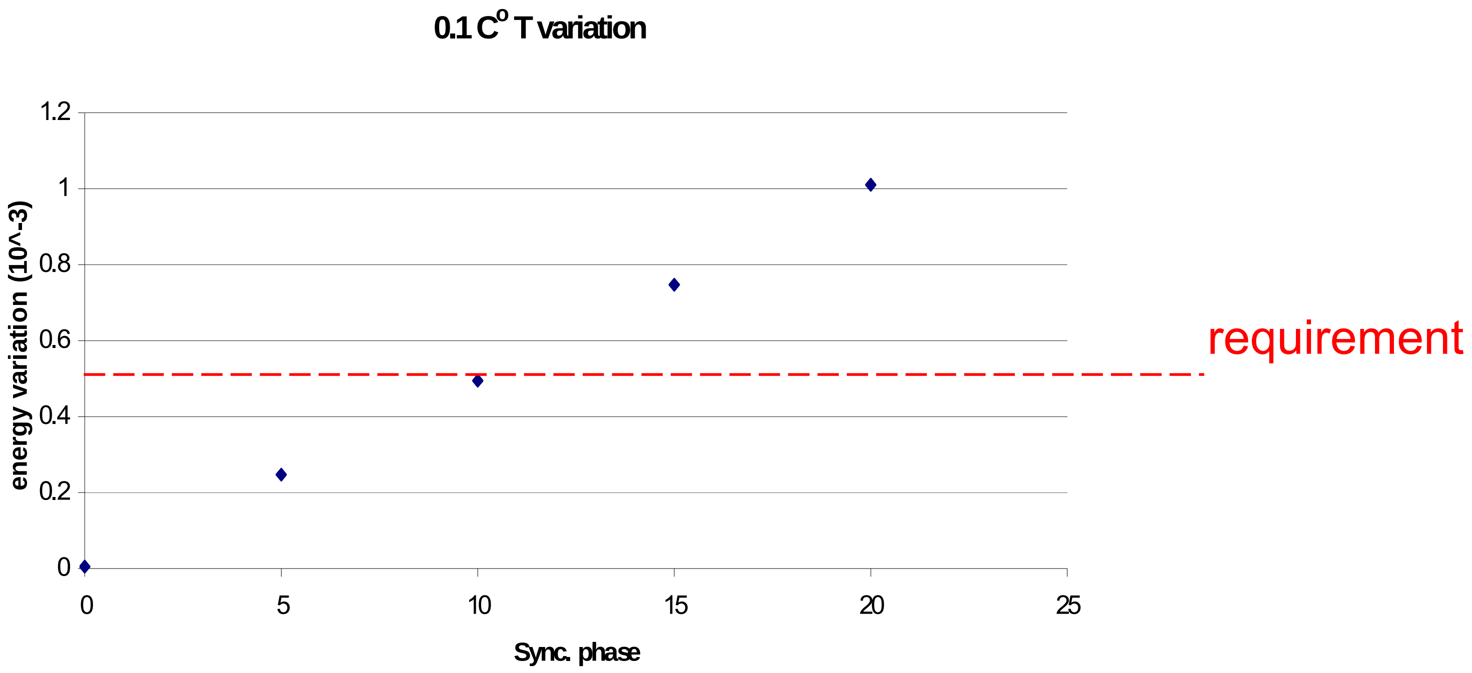
Thermal isotropic expansion

Assumption: isotropic dilatation for small variation of the temperature of the cooling water

Conservative approach: same T variation for the full linac (present design; one inlet for one linac)

Dilatation has two effects on phase:

1) Elongation of the structure; 1D problem, negligible effect
2) Detuning and consequent phase error of each cell; 3D problem, dominant effect



The average gradient variation is “equivalent” to 0.2 deg phase jitter(*) *(drive beam-main beam phase)*

(*) In the case of synchronous phase = 8 deg

Conclusions

- RF mismatching, phasing errors and bookshelf are critical for structure tolerances
- Bookshelf for structures in disks requires equivalent tolerances (~ 180 μrad)
- Variation of the cooling water temperature could generate beam energy variations; (feedback system ?)
- For a massive production we should avoid mechanical tuning (deformation); Can we partially compensate by changing slightly the absolute position of a module?

Thanks to: S. Barakou,j. Huopana, R. Nousiainen, D. Schulte,