

## Structure fabrication and assembly tolerances

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## Tolerances of the structures

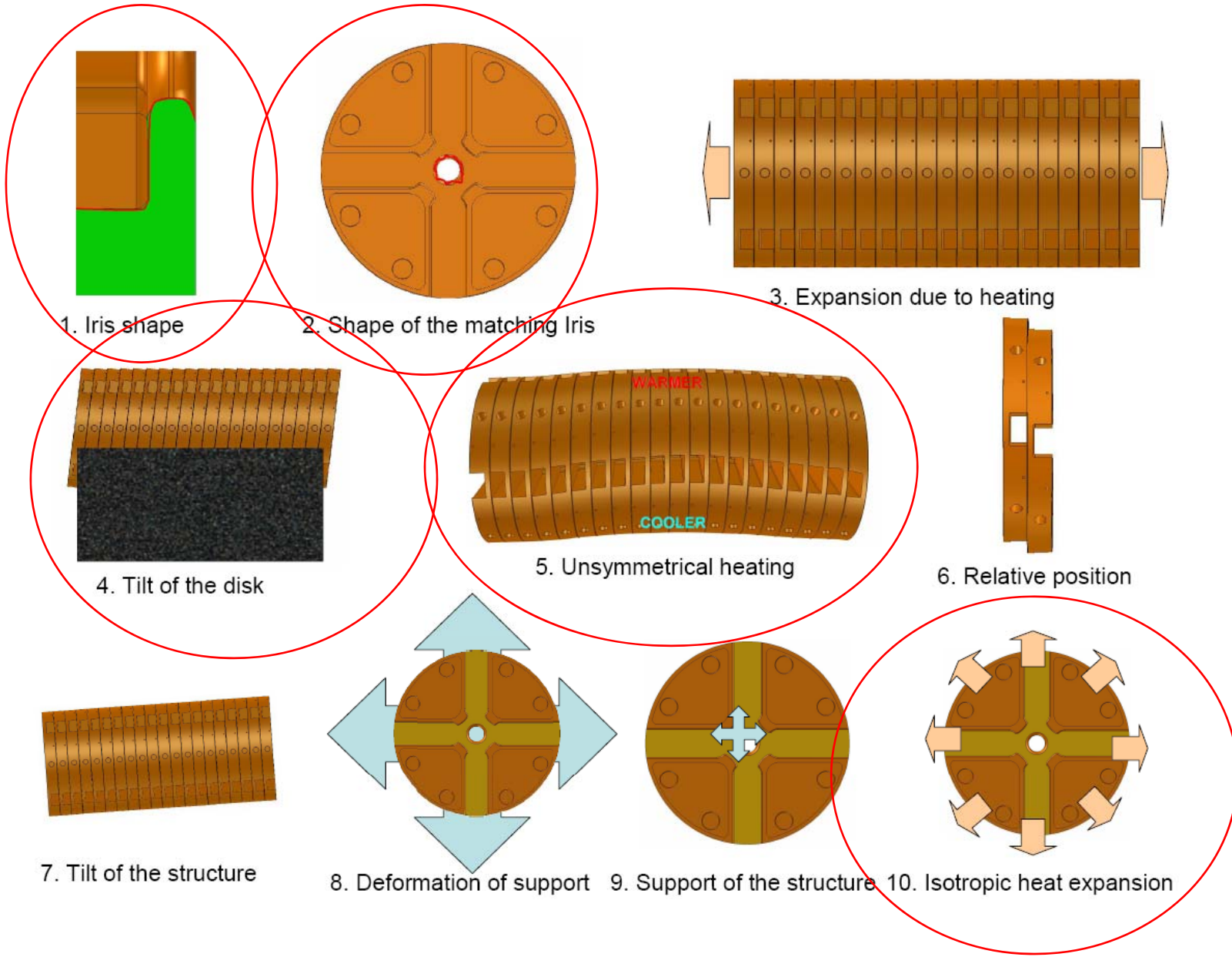
### 4 kinds of tolerances:

- *Machining* ( $\Delta x, \Delta y, \Delta z$ )
- *Assembly* ( $\Delta x, \Delta y, \Delta z$ )
- *Alignment* ( $\Delta x, \Delta y, \Delta z$ )
- *Operation [Cooling]* ( $\Delta T$  (t) water in,  $\Delta T$  (z))

### 4 kinds of problems:

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

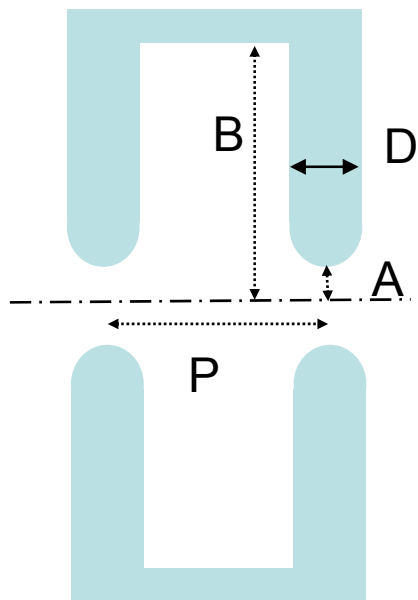
Item	Effect of the item	Performance	Cause				Solution	Magnitude of tolerance	Criticality	Comments	Scheme
			Mach.	Assem.	Align.	Oper.					
<b>SHAPE</b>											
Shape of an Iris	dephasing	lower efficiency	x				Tuning	$\pm 0.001$ mm	high	local	1
Shape of the matching Iris	mismatching	lower efficiency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



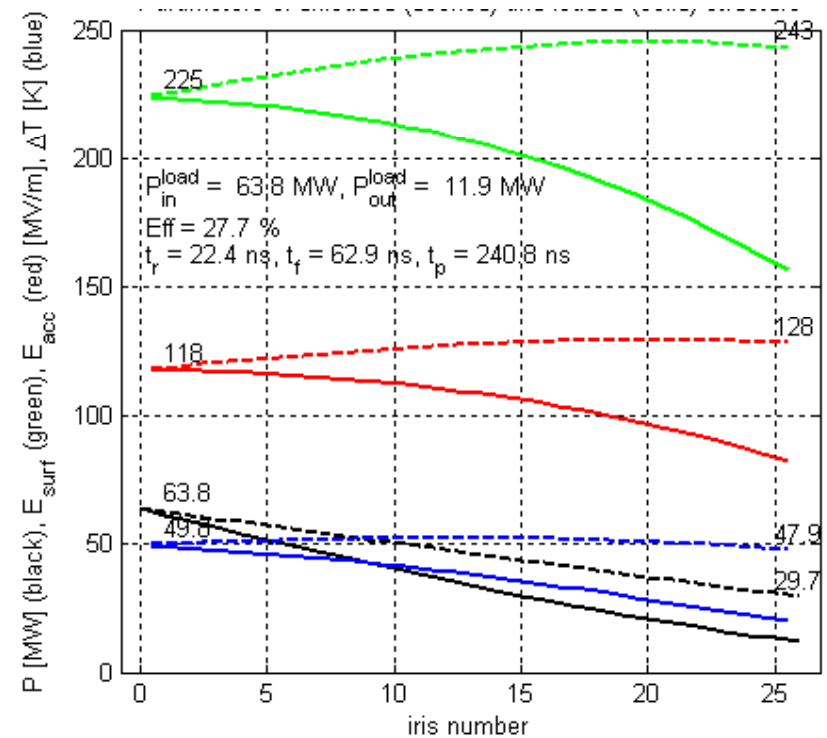
## Structure Shape

**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 (dB) to get  $S_{11} < -30$  dB is ~1.5 micron, if any tuning is applied.



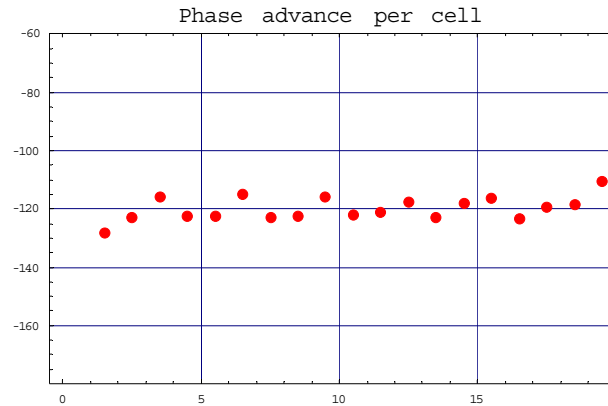
The sensitivity of the phase advance to the main geometrical parameters has been computed for the different cells of the CLIC\_G structure. Strong dependence on the group velocity:  $v_g/c(\%)$ : 1.66 (first cell) 0.83 (last cell)



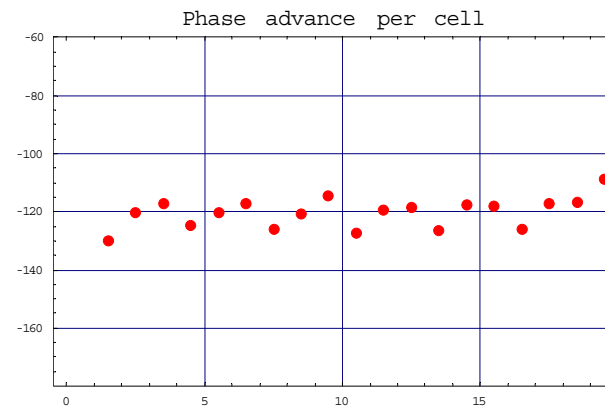
CLIC\_G      Courtesy of A. Grudiev

## 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**

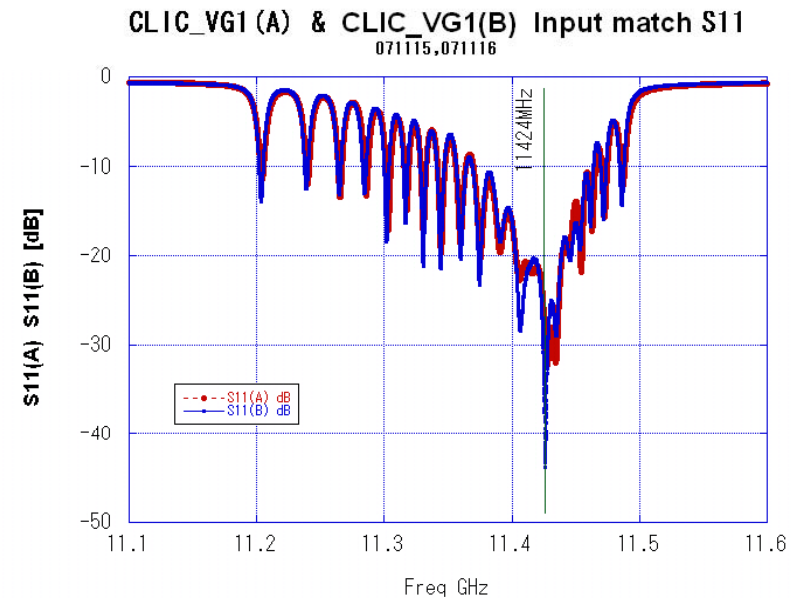


Average phase advance per cell  
-119.943 degrees / cell

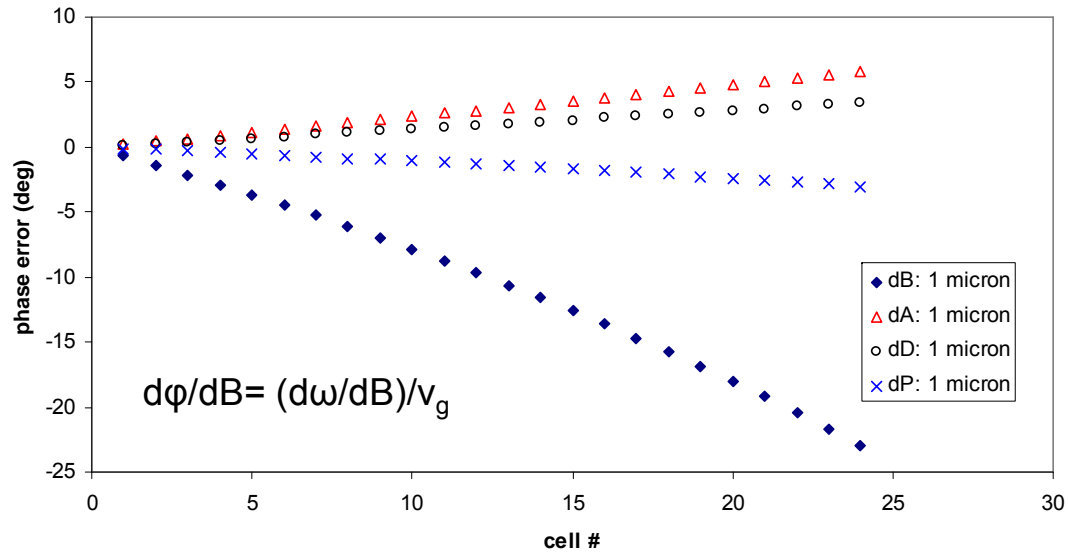


Average phase advance per cell  
-120.424 degrees / cell

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



## Structure Shape (systematic error)

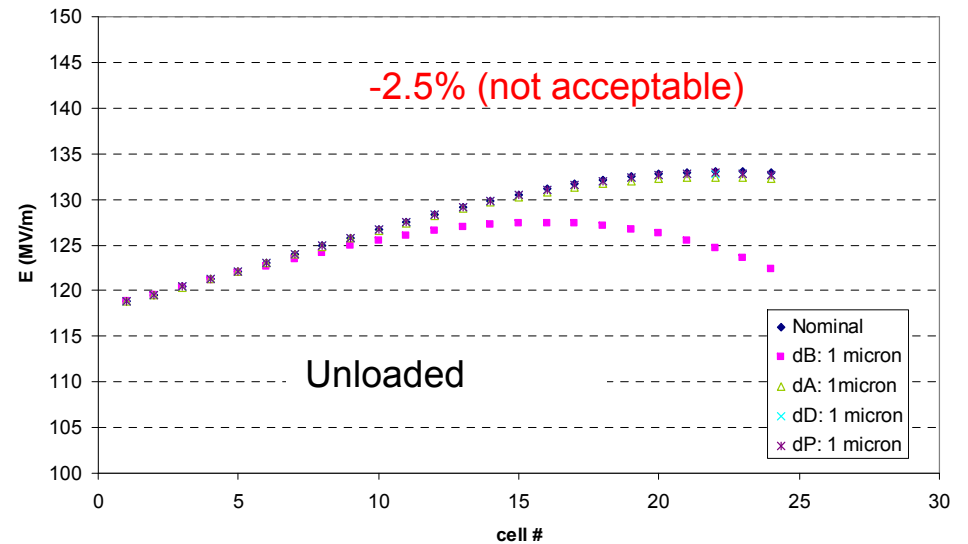
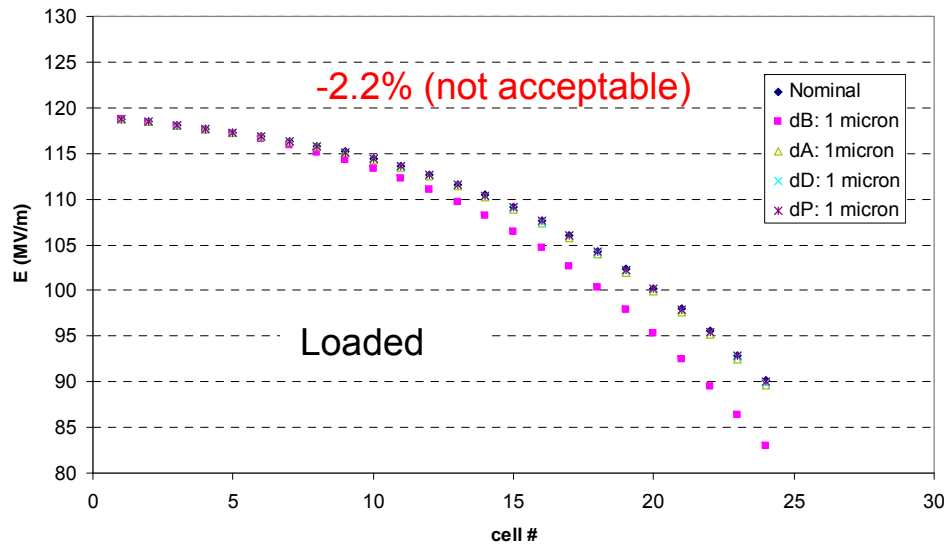


	df/dB (radius) [MHz/ $\mu\text{m}$ ]	dph./df [deg/MHz]
cell1	1.1	0.6
cell24	1.0	1.2

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

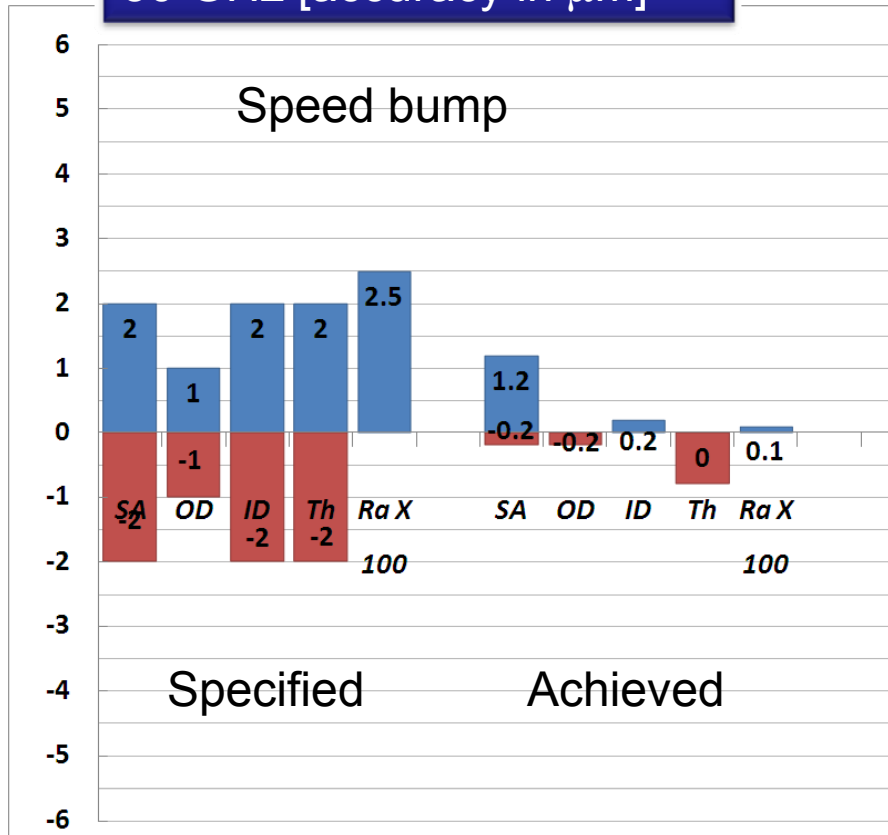


The phase error implies a variation on the effective accelerating field

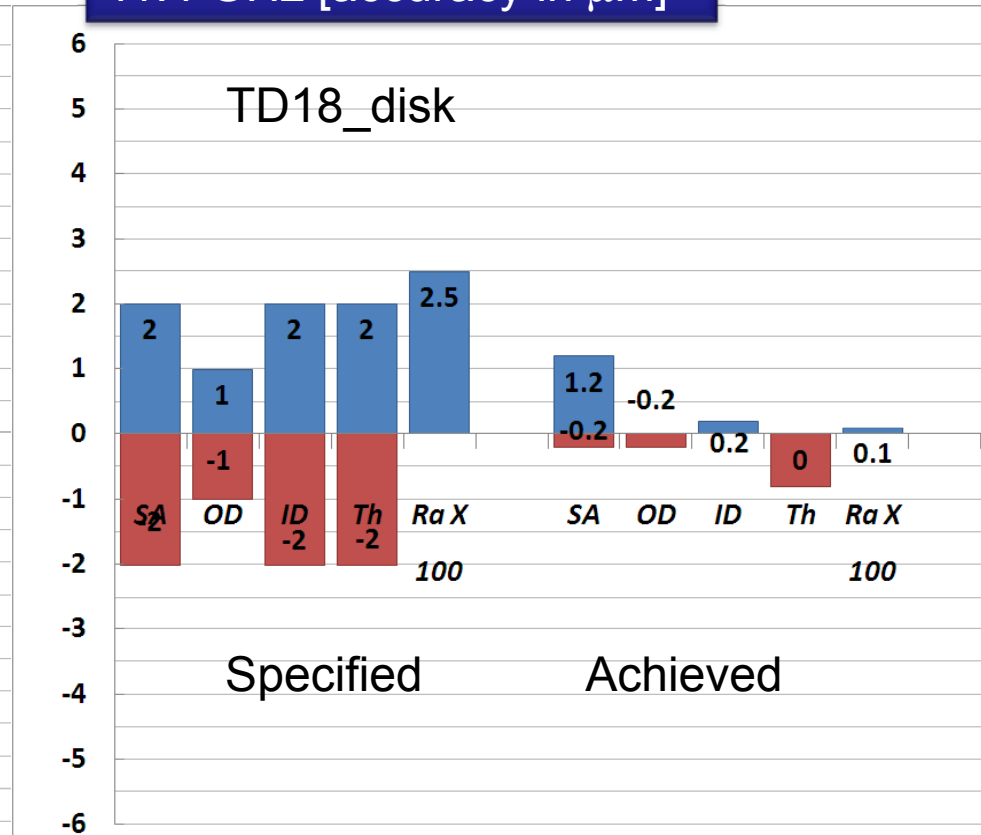


# Achieved accuracy (disk)

30 GHz [accuracy in  $\mu\text{m}$ ]



11.4 GHz [accuracy in  $\mu\text{m}$ ]

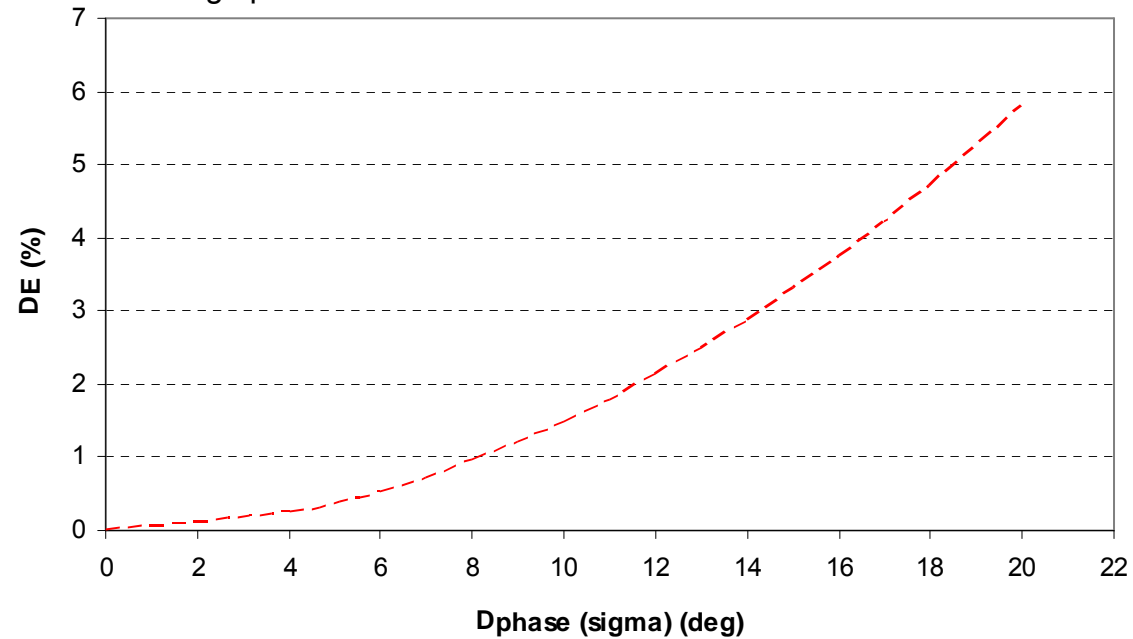


SA: iris shape accuracy  
 OD: outer diameter  
 ID: inner diameter  
 Th: iris thickness  
 Ra: roughness



## Structure Shape (random error)

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

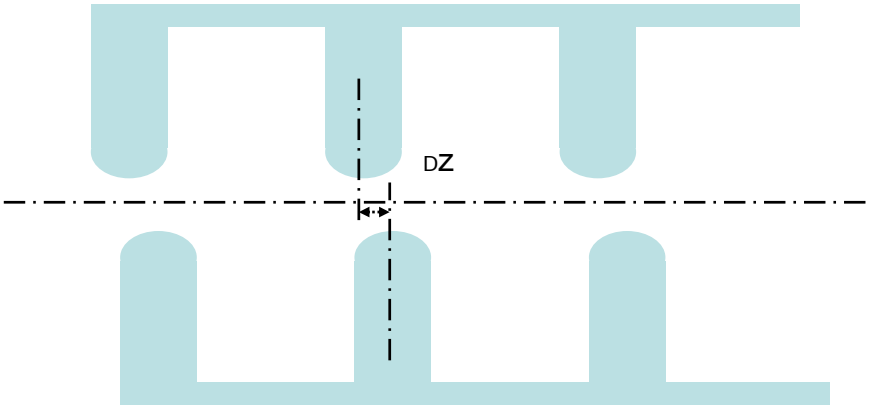


Acceptable average gradient error:  $\sigma=2\%$  (D. Schulte)

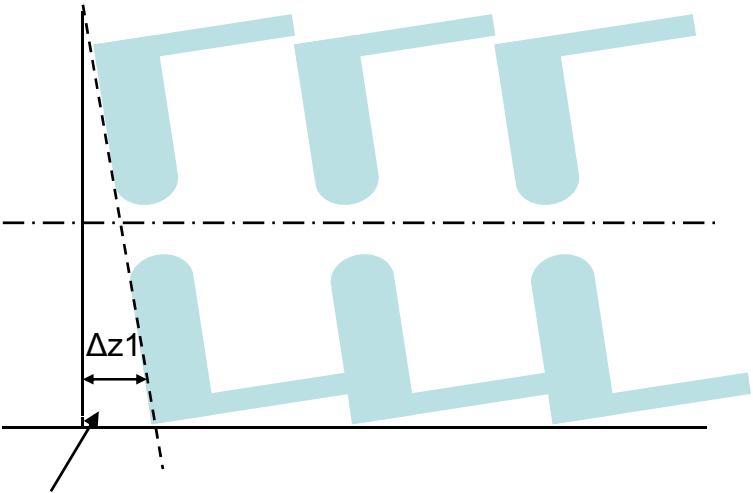


$\Delta B < 17$  microns (first cell); 9 microns (last cell)

# Bookshelf or longitudinal misalignment of half-structure



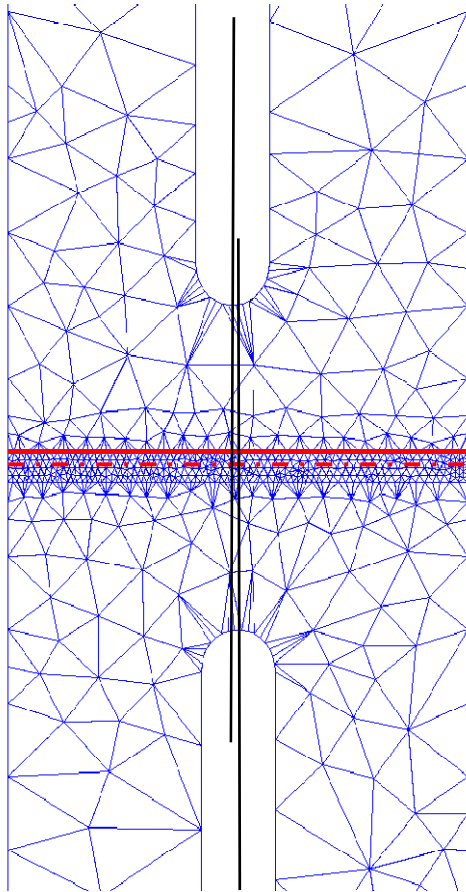
Structure in quadrants  
problem mainly for the **machining** and **assembly**



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

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

## Bookshelf or longitudinal misalignment of half-structure



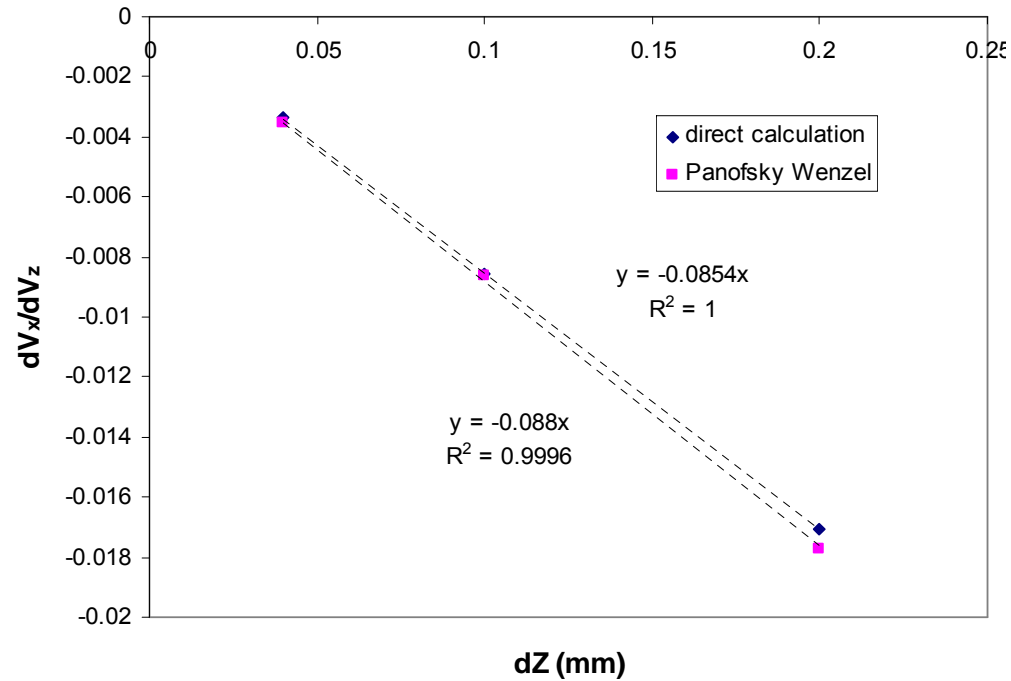
Middle cell of CLIC\_G  
(a=2.75mm)

$$V_x := \int_0^{Z_{end}} [(EX(z) - HY(z)) \cdot \exp[i \cdot (\kappa \cdot z - \phi)]] dz$$

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

Direct kick calculation

Panofsky Wenzel  
(cross-check)



$dV_x/dV_z \sim 0.087 \cdot dZ$   
computed

$dV_x/dV_z = dZ / (4 \cdot a) = 0.09 \cdot dZ$

Prediction (Daniel)

Equivalent bookshelf  
angle:  $\alpha = dZ / 2a$

Tolerances: 1 micron or  
180  $\mu$ rad

## Thermal isotropic expansion

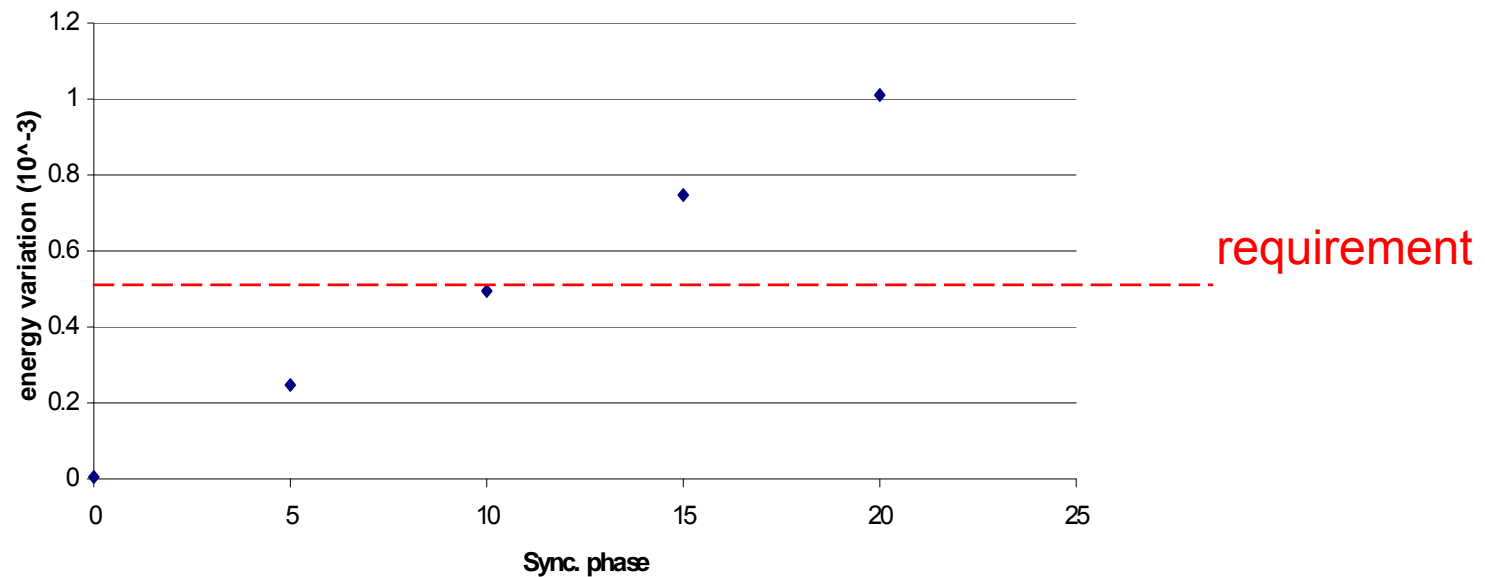
*Assumption: isotropic dilatation for small variation of the temperature of the cooling water*

*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

0.1 C° T variation



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 ( $\sim 180 \mu\text{rad}$ )
- 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,