CLIC accelerating structures:
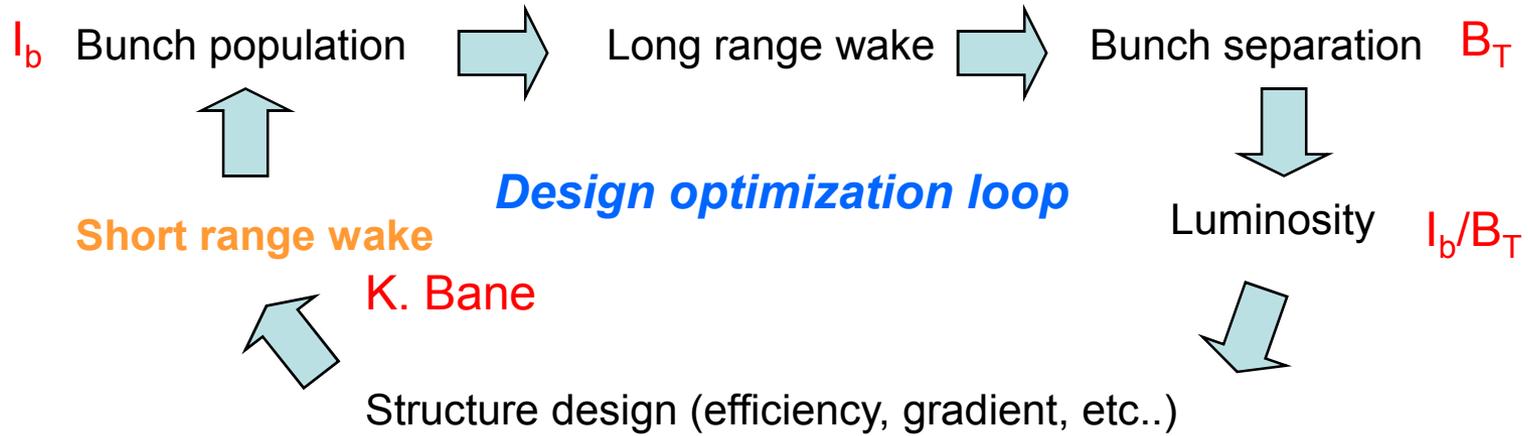
study of the tolerances and short range wakefield considerations

R. Zennaro CERN

RF Design optimization

I_b Bunch population $\Rightarrow$ Long range wake $\Rightarrow$ Bunch separation B_T

Design optimization loop

Short range wake

K. Bane

Luminosity I_b/B_T

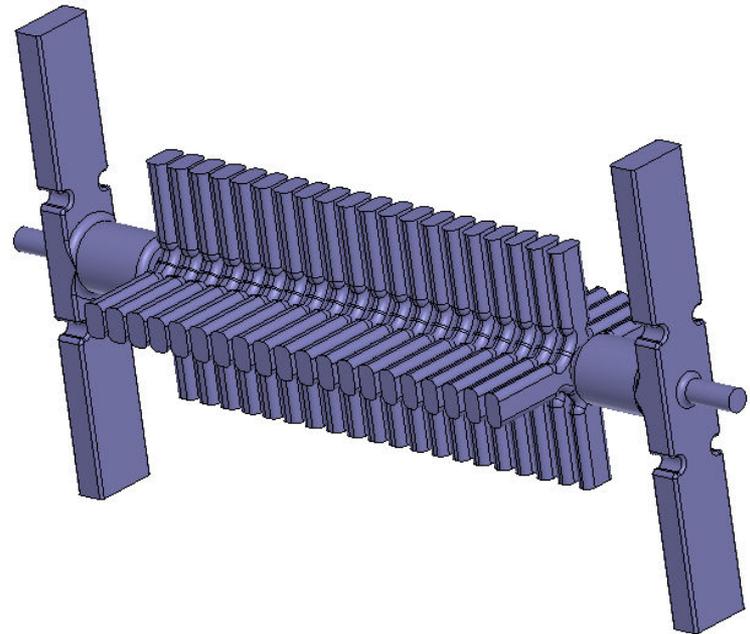Structure design (efficiency, gradient, etc..)
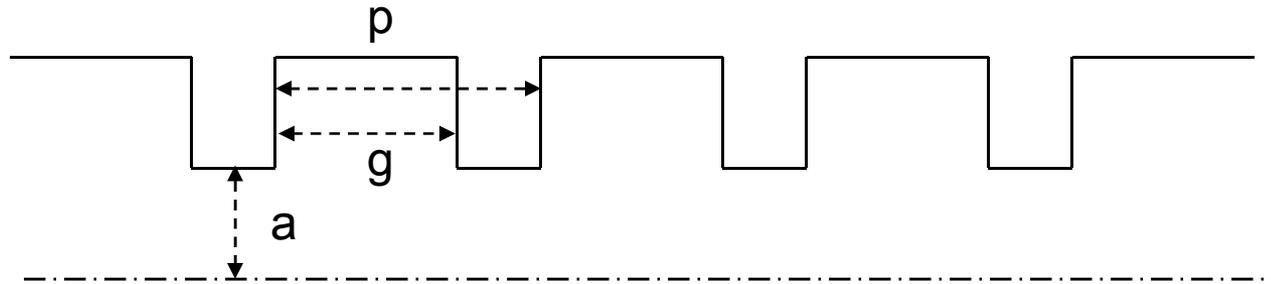
Tolerance study

Feasibility , selection of the technology

Disk   Quadrant

Karl Bane short range wake for periodic geometric

Longitudinal wake function

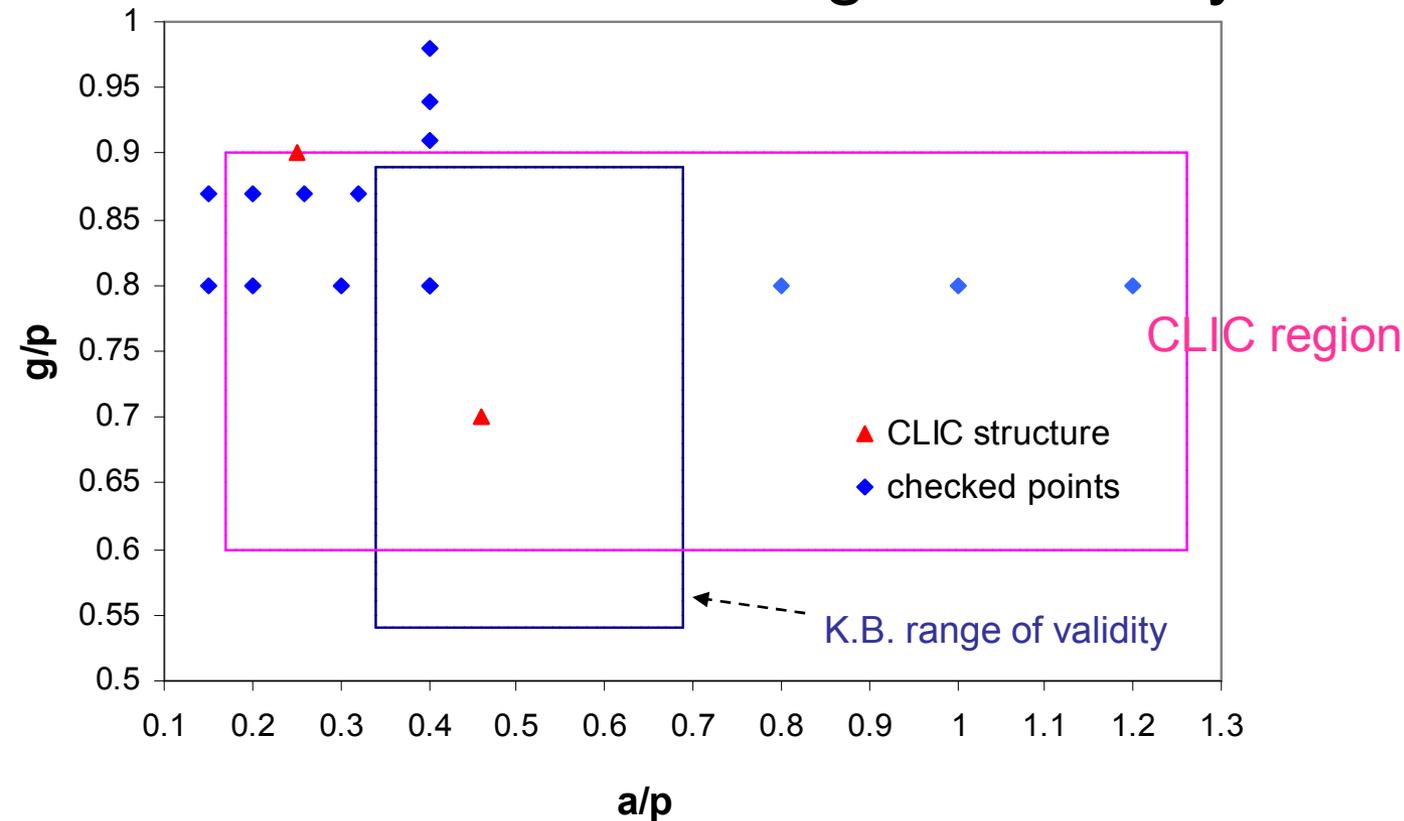$$W(s) = \frac{Z_0 c}{\pi a^2} \exp\left(-\sqrt{s/s_1}\right)$$

$$s_1 = 0.41 \frac{a^{1.8} g^{1.6}}{p^{2.4}}$$

Transverse wake function

$$W_x(s) = \frac{4 Z_0 c s_0}{\pi a^4} \left[1 - \left(1 + \sqrt{\frac{s}{s_0}}\right) \exp\left(-\sqrt{\frac{s}{s_0}}\right)\right]$$

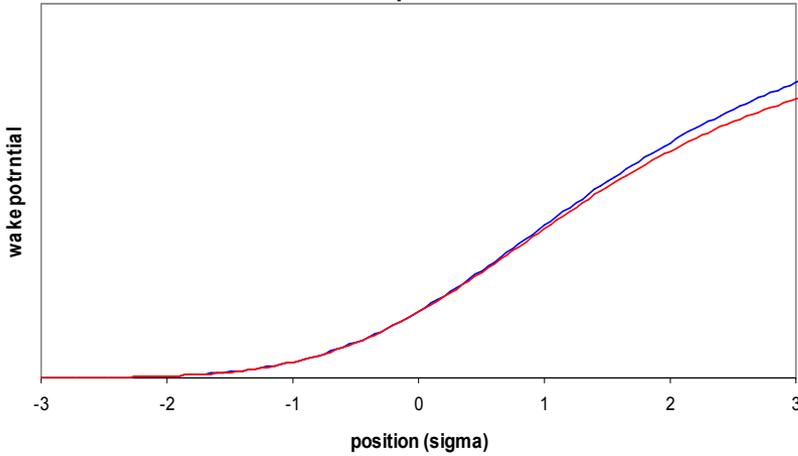$$s_0 = 0.17 \frac{a^{1.79} g^{0.38}}{p^{1.17}}$$

Range of validity

The validity of K.B. formulas has been investigated in the full CLIC region by using the 2D code ABCI:
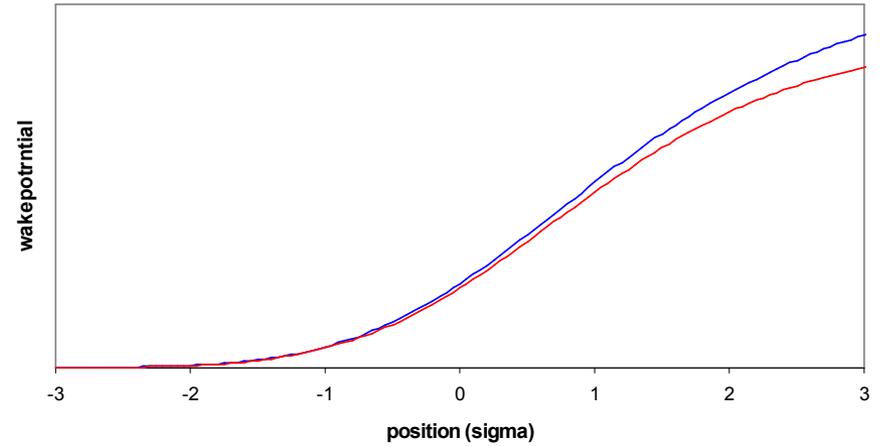
✓ Good results for the longitudinal wake

✓ Some discrepancies for the transverse wake for small a/p
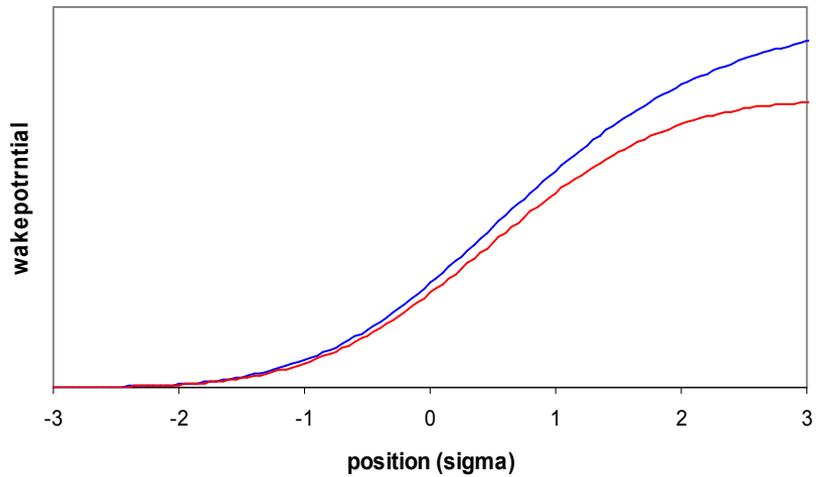
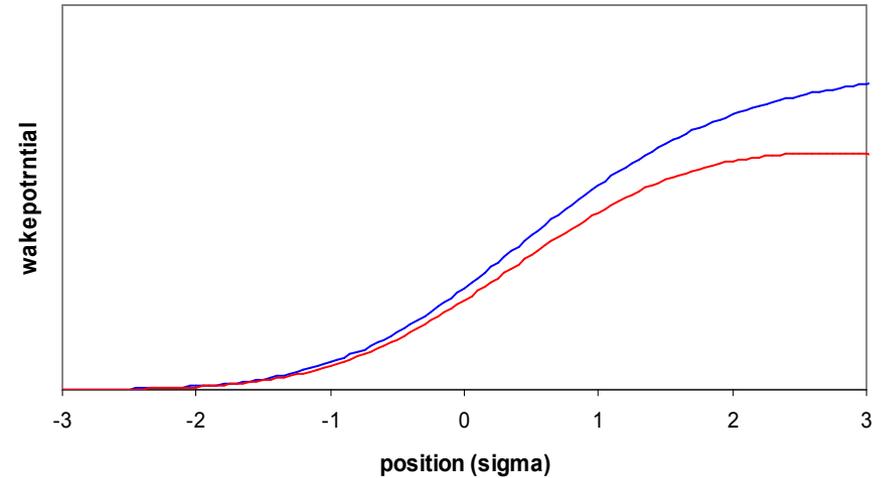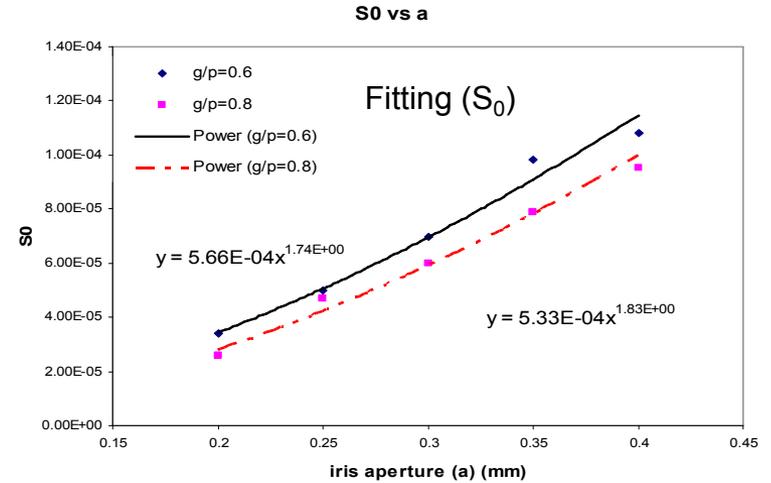# Transverse K.B.: Range of validity (a/p)

a/p=0.4

wakepotrntial

position (sigma)

a/p=0.3

wakepotrntial

position (sigma)

a/p=0.2

wakepotrntial

position (sigma)

a/p=0.16

wakepotrntial

position (sigma)

Fitting (tentative)

b*S0 vs a

Dependence on *a*

S0 vs a

$y = 3.64586E-05x^{1.69193E+00}$
$R^2 = 9.96246E-01$

$y = 3.47171E-05x^{1.74656E+00}$
$R^2 = 9.96557E-01$

Dependence on *g*

- ◆ g/p=0.8
- ■ g/p=0.6
- — Power (g/p=0.8)
- — Power (g/p=0.6)

a (mm) [p=5mm]

Fitting (S_0)

- ◆ g/p=0.6
- ■ g/p=0.8
- — Power (g/p=0.6)
- — ·— Power (g/p=0.8)

$y = 5.66E-04x^{1.74E+00}$

$y = 5.33E-04x^{1.83E+00}$

iris aperture (a) (mm)
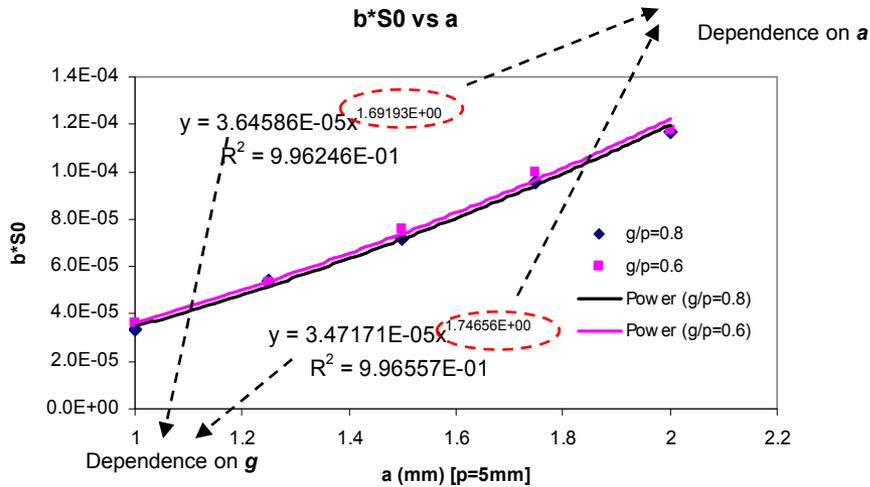
$$W_x(s) = b\frac{4Z_0 c s_0}{\pi a^4}\left[1 - \left(1 + \sqrt{\frac{s}{s_0}}\right)\exp\left(-\sqrt{\frac{s}{s_0}}\right)\right]$$

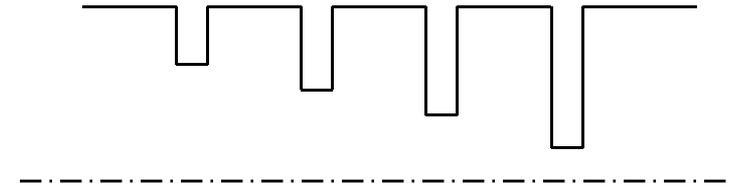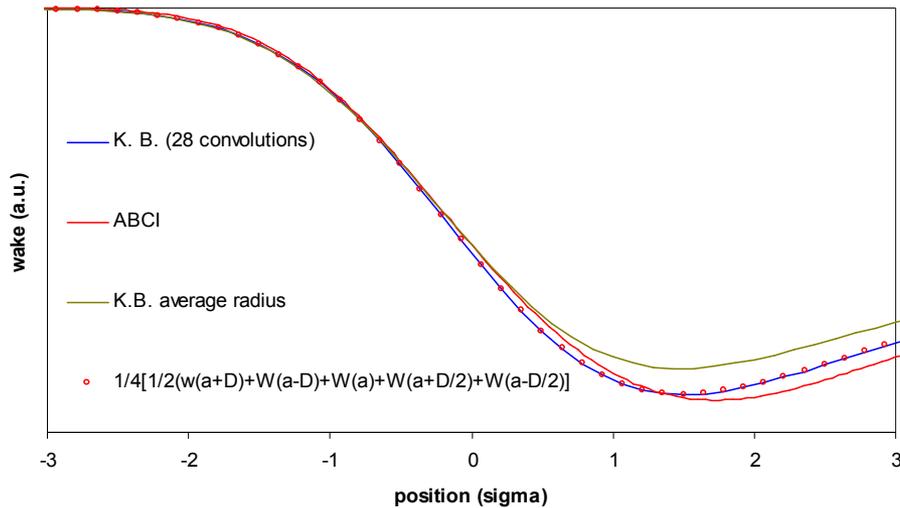Very good fitting with two free parameters fitting (b, S0)

Poor fitting with a single free parameter (S0) but in the full range

Next: tentative of fitting on a smaller range limited to X band

$$s_0 = 0.17\frac{a^{1.79} g^{0.38}}{p^{1.17}}$$

$$s_0 = 0.0836\frac{a^{1.77}}{g^{0.7} p^{0.07}}$$

$$b = 1.17\frac{g^{0.46}}{a^{0.08} p^{0.38}}$$

Non-periodic structures: longitudinal wake

non-periodic structure (28 cells) longitudinal wake

- K. B. (28 convolutions)
- ABCI
- K.B. average radius
- ∘ 1/4[1/2(w(a+D)+W(a-D)+W(a)+W(a+D/2)+W(a-D/2)]

wake (a.u.) / position (sigma)

Example: $0.335 < a/p < 0.603$; 28 cells

Non-periodic structure (28 cells), transverse wake

- K.B. (28 convolutions)
- ABCI
- K.B.; average radius
- ∘ 1/4[1/2(w(a+D)+W(a-D)+W(a)+W(a+D/2)+W(a-D/2)]

wake (a.u.) / position (sigma)
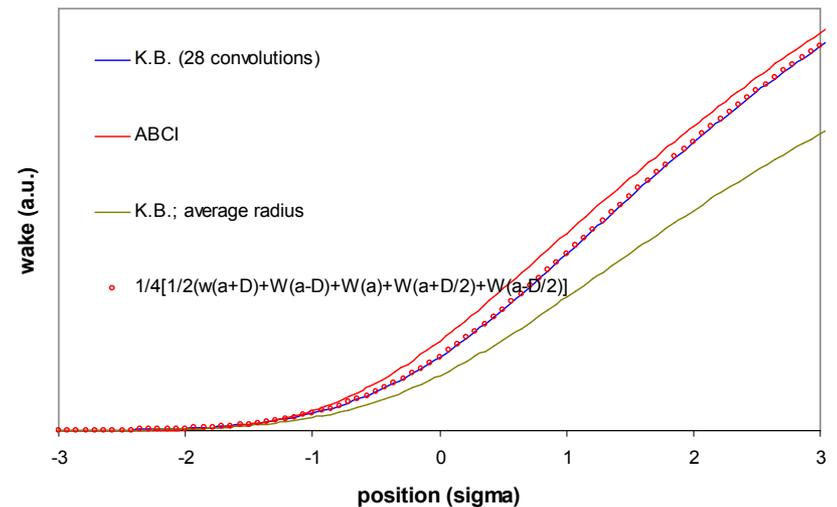
K.B. provides good results also for terminated tapered structures

Rounded irises

Longitudinal wake

wake potential (a.u.)

— combination of K.B.
— ABCI
— K.B a=2

position (sigma)
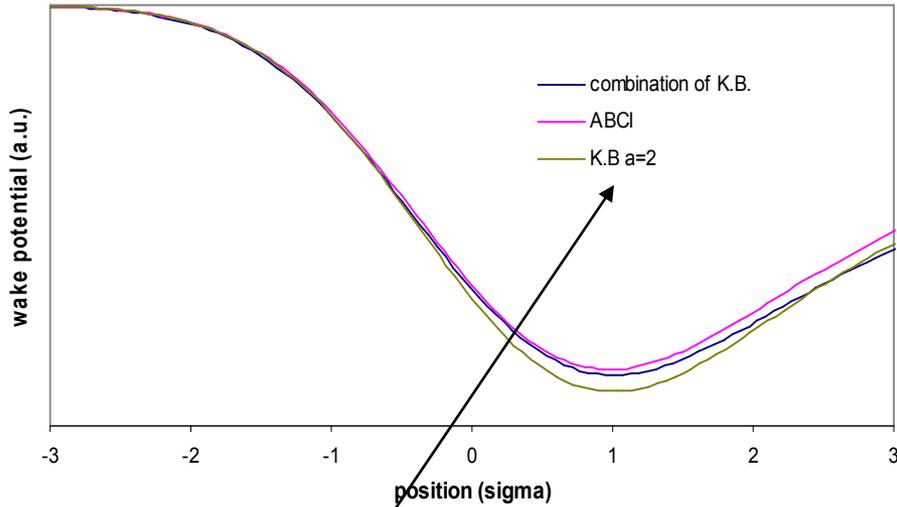
*In this case a=2mm is the minimum distance to the axis*
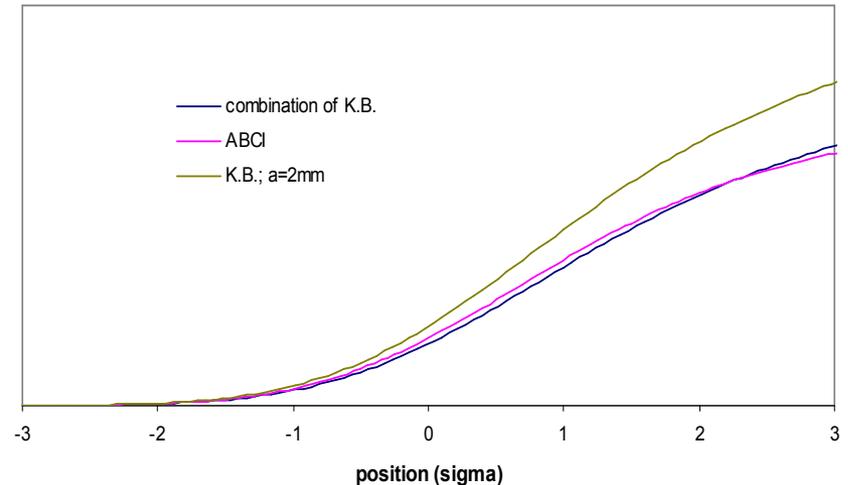
The result is not bad for longitudinal wake…

The rounding of the irises seems to be the main approximation of K.B. formulas

K.B. is valid for rectangular irises but the reality is different…

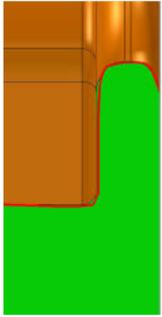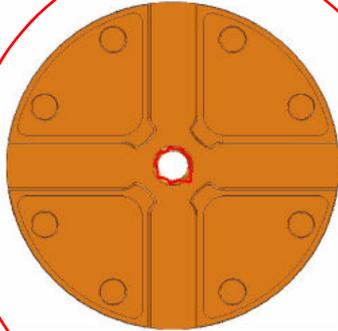Let's consider the combination of different wakes originated by different geometries

Transverse wake

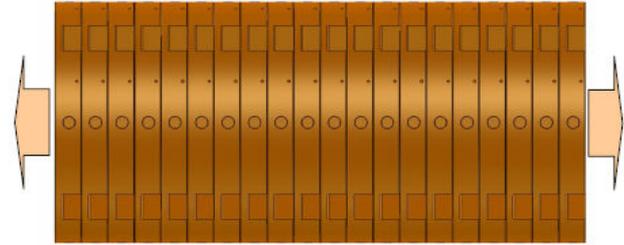— combination of K.B.
— ABCI
— K.B.; a=2mm
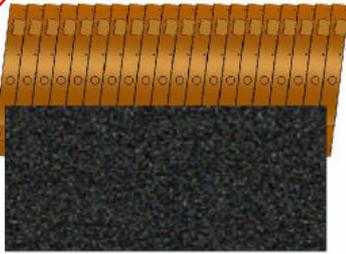
position (sigma)
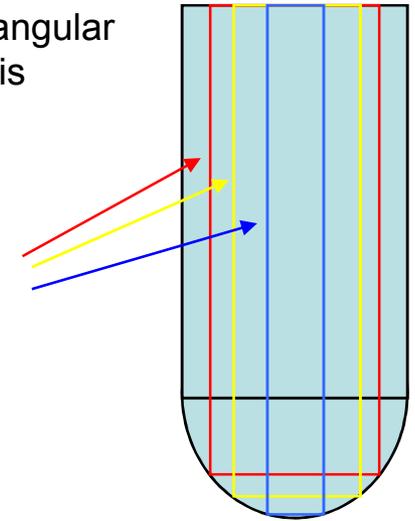
…and better for transverse wake

1. Iris shape

2. Shape of the matching Iris

3. Expansion due to heating

4. Tilt of the disk

5. Unsymmetrical heating
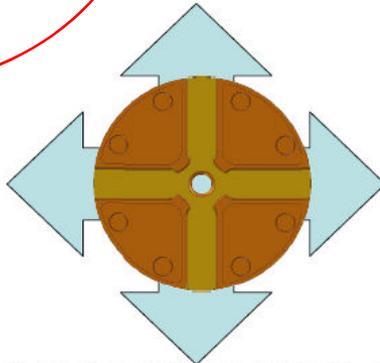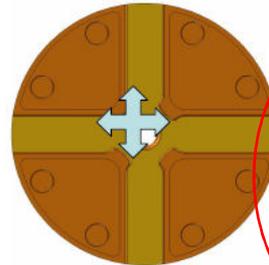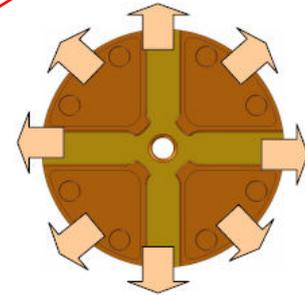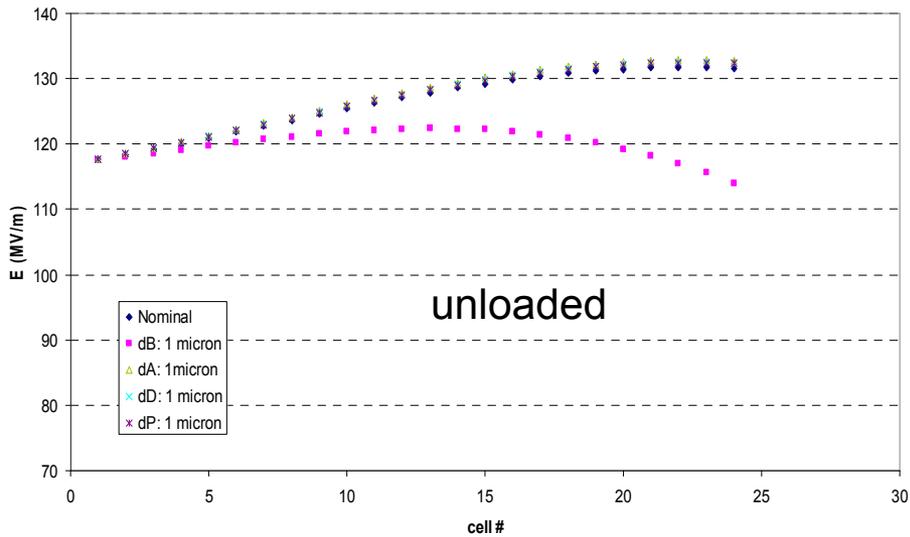
WARMER

COOLER

6. Relative position
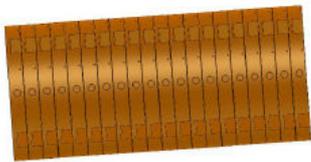
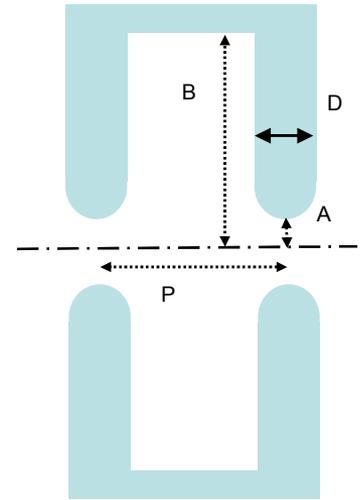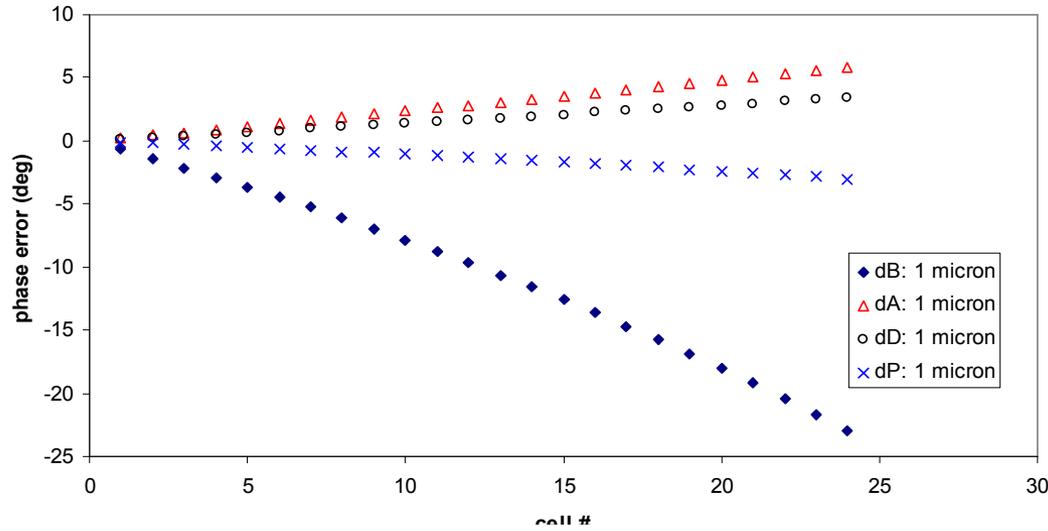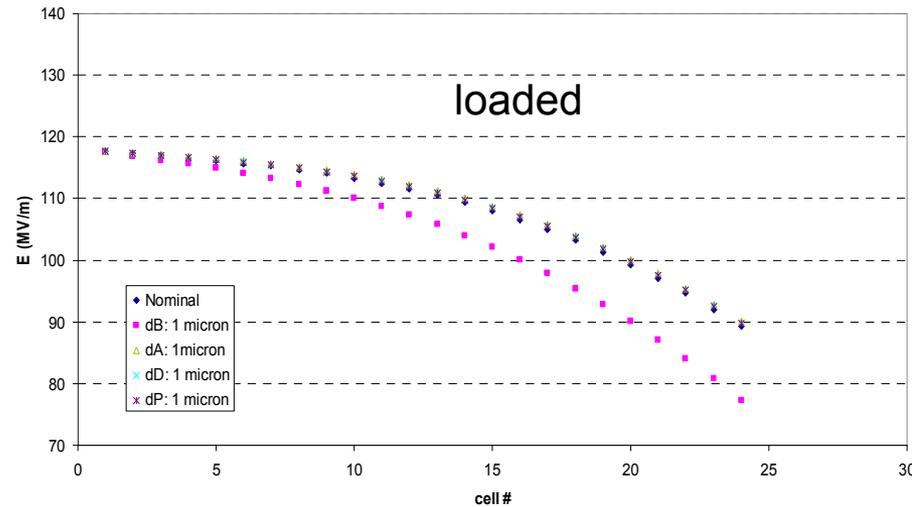7. Tilt of the structure

8. Deformation of support

9. Support of the structure

10. Isotropic heat expansion

Phase slip: systematic errors

Integrated gradient -5.1%

Integrated gradient -4.7%

BD goal: 2%...the tolerance for the diameter (2B) should be 1 micron or better

Phase slip: random errors

$$\sigma_{<\varphi>} = \overline{\Delta}_{\varphi} \cdot \overline{\Delta}_{B}$$

$$\overline{\Delta}_{B\,max} = \frac{\sqrt{24}}{\left|\overline{\Delta}_{\varphi}\right|} \overline{\Delta}_{\varphi}$$

Vector of the structure   Vector of the errors   Most critical distribution
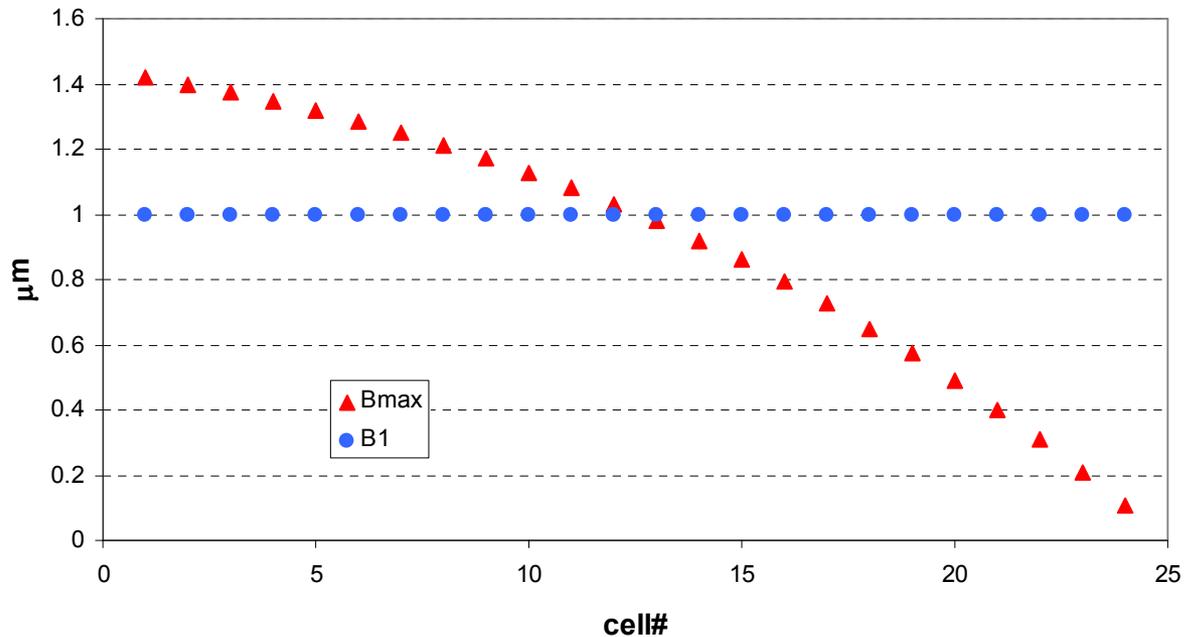
Results:

Most critical distribution: average phase slip: 11.7 degrees

1 micron (ΔB) systematic error: 10.7 degrees

Matching of the cells and standing wave components (no phase slip)

A tolerance of 1 micron in the diameter (2*B) origins a VSWR~ 1.03; largely good enough for BD and acceptable for BDR considerations

Bookshelf or longitudinal misalignment of half-structure
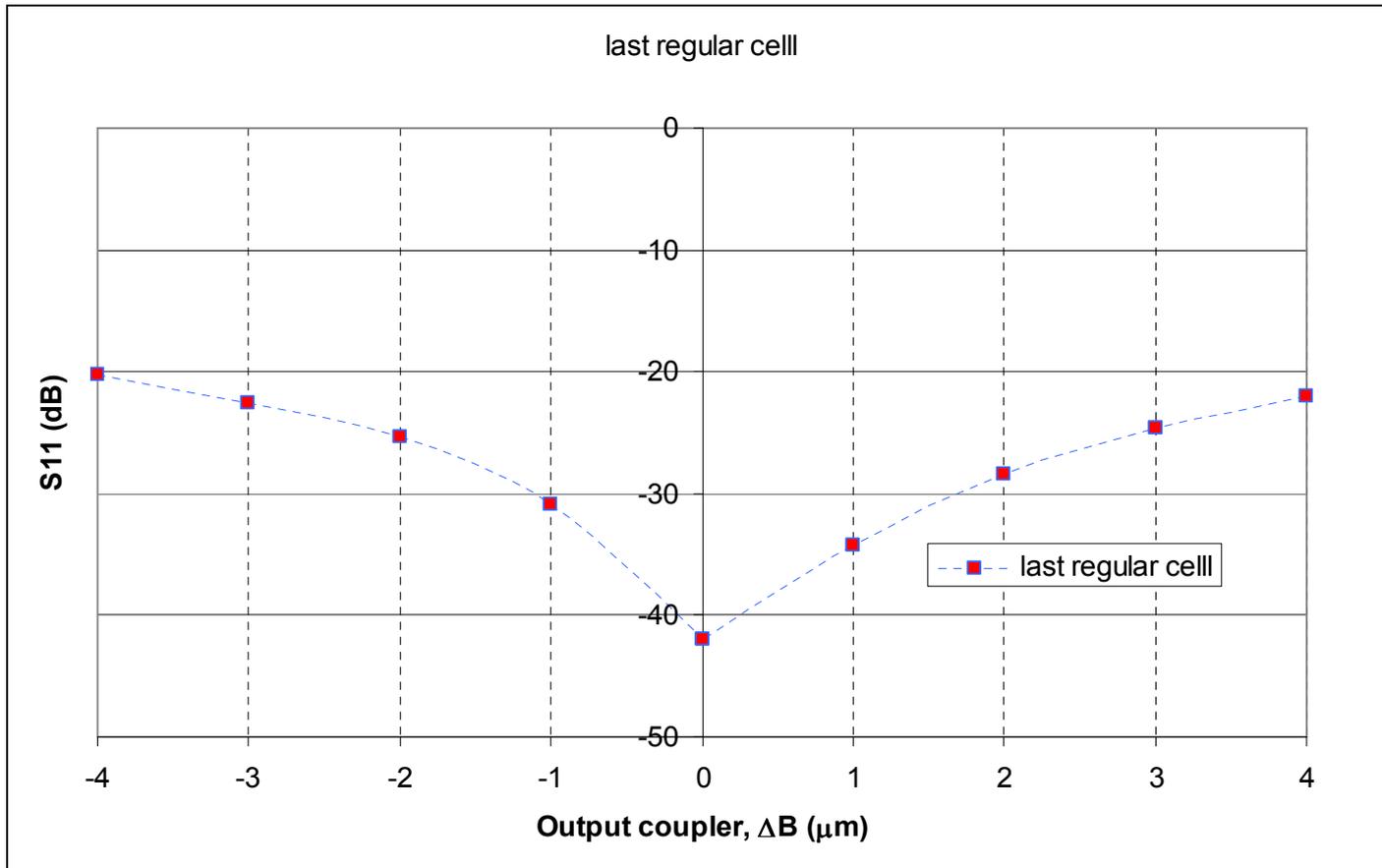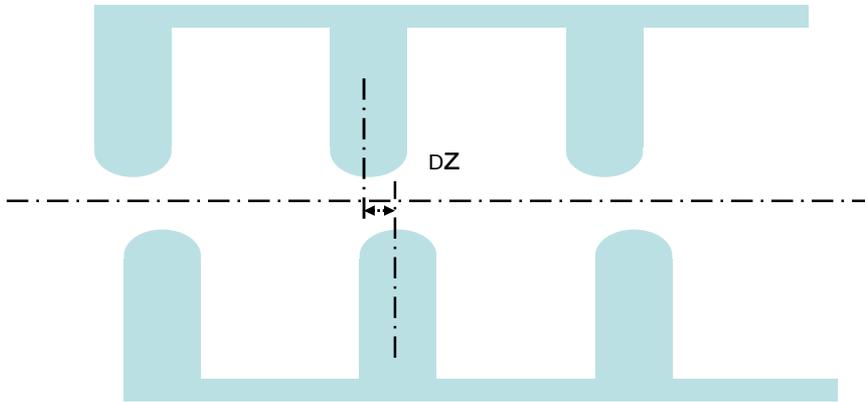
Structure in quadrants

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

Structure in disks

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

$Δz1 ≈ D/a* Δz$

Bookshelf or longitudinal misalignment of half-structure

Middle cell of CLIC_G
(a=2.75mm)

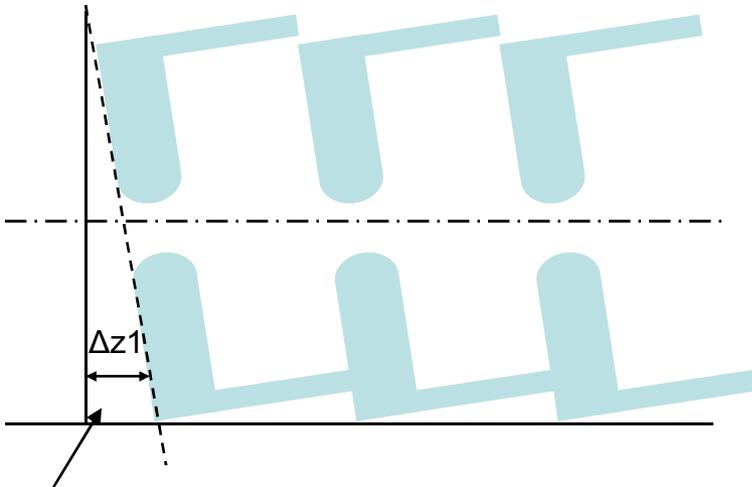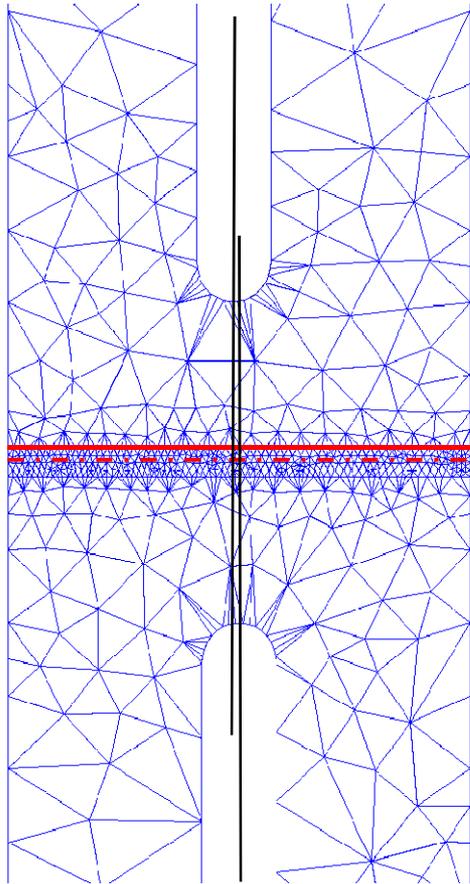$$Vx := \int_0^{Zend} \left[(EX(z) - HY(z)) \cdot \exp\left[i \cdot (\kappa \cdot z - \phi) \right] \right] dz$$

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

Direct kick calculation

Panofsky Wenzel
(cross-check)

$y = -0.0854x$
$R^2 = 1$

$y = -0.088x$
$R^2 = 0.9996$
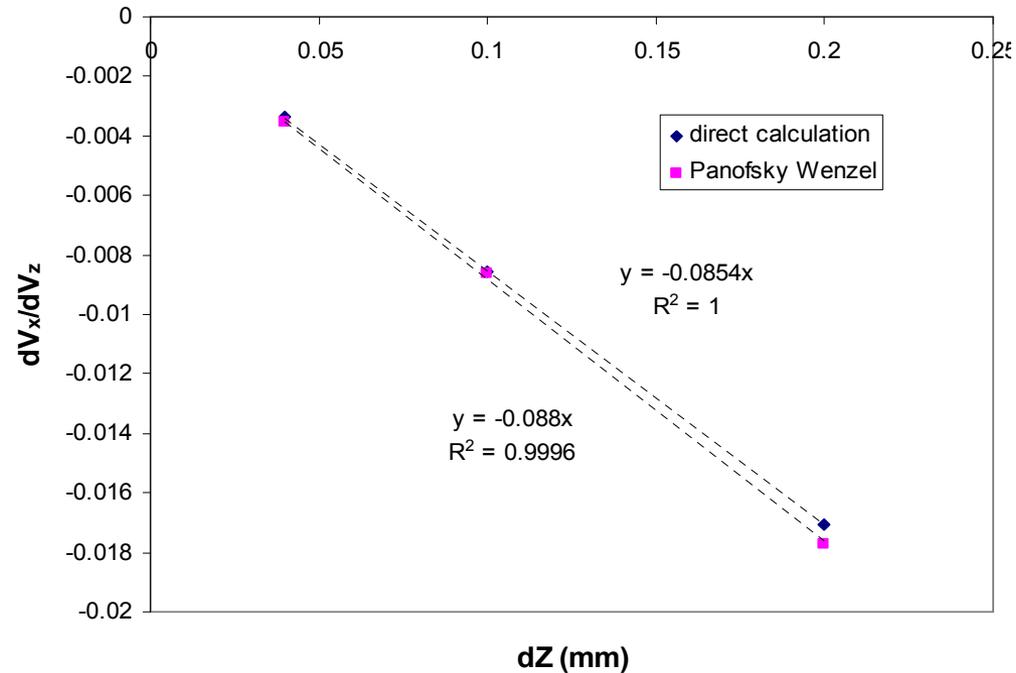
DVx/DVz~0.087*Dz
computed

DVx/DVz=Dz/(4*a)=0.09*Dz

Prediction

Equivalent bookshelf
angle: α=dz/2a

Tolerances: 1micron or
180 µrad (achievable)
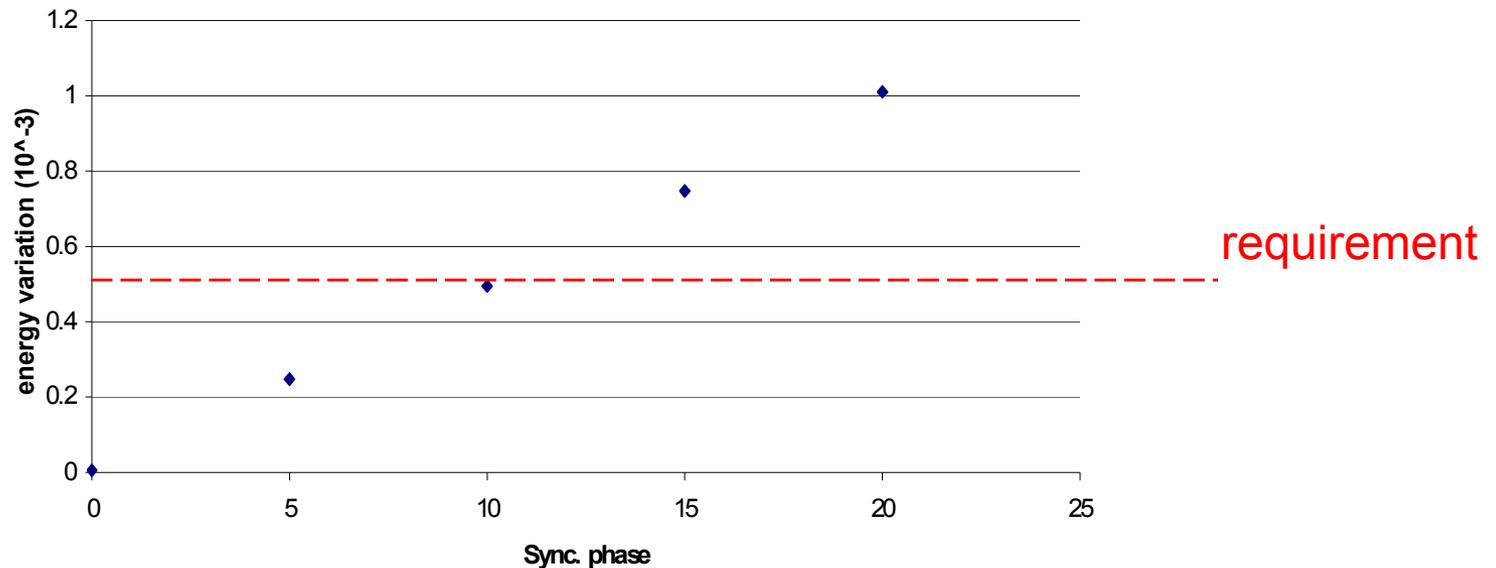
Thermal isotropic expansion

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^o T variation

(chart: energy variation (10^-3) vs Sync. phase; red dashed line labeled "requirement" at ~0.5)

energy variation (10^-3) — y-axis: 0, 0.2, 0.4, 0.6, 0.8, 1, 1.2

Sync. phase — x-axis: 0, 5, 10, 15, 20, 25

requirement

The average gradient variation is "equivalent" to 0.2 deg phase jitter(*) *(drive beam-main beam phase)*
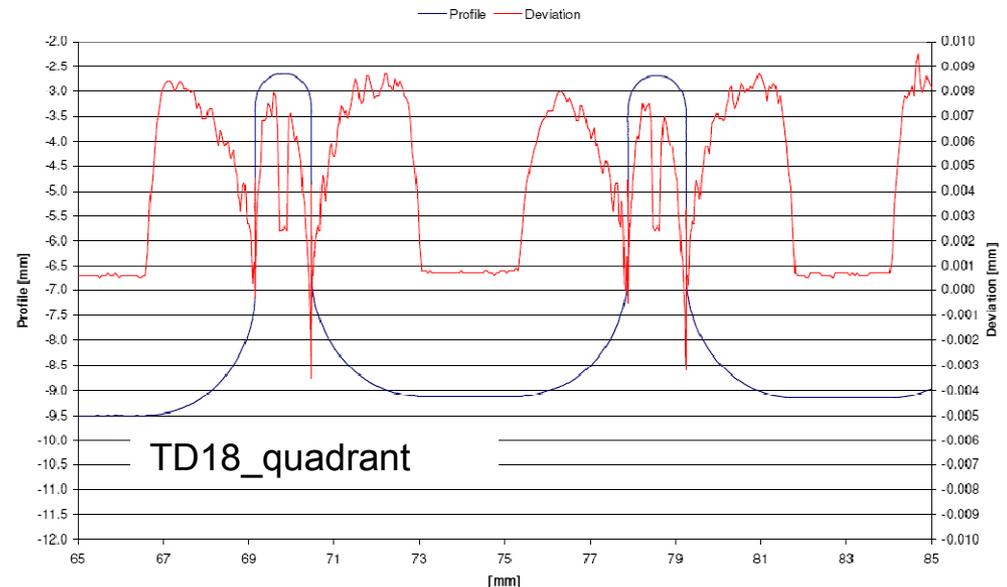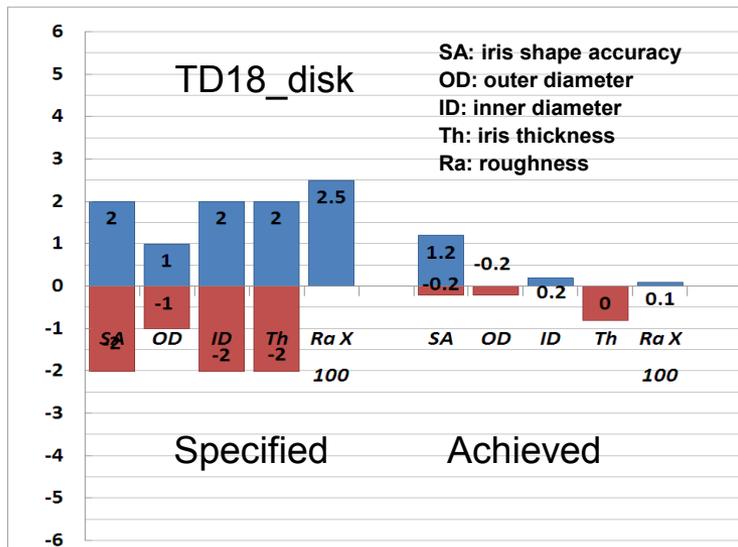
(*) In the case of synchronous phase = 8 deg

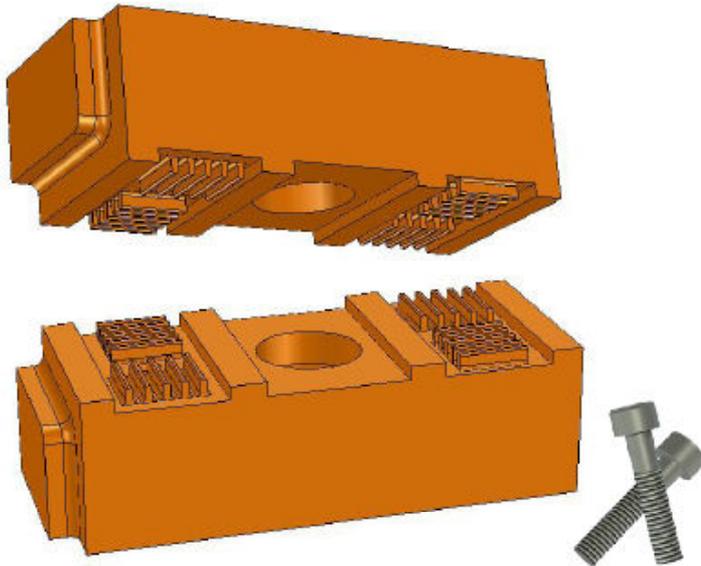# Structure production: what we have achieved
(courtesy of S. Atieh)

Metrology results of two structures manufactured by the same company with the equivalent RF design.

Two different technologies: disks and quadrants

TD18_disk

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

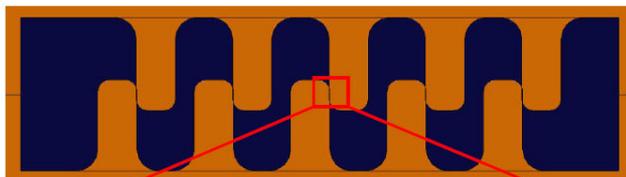Specified   Achieved

TD18_quadrant

Assembly test for structures in quadrants: elasting averaging
(courtesy of J. Huopana)

Principle is to use multiple contacts and elasticity of the material to decrease the effects of manufacturing errors in assembly

Overlap of 10 μm
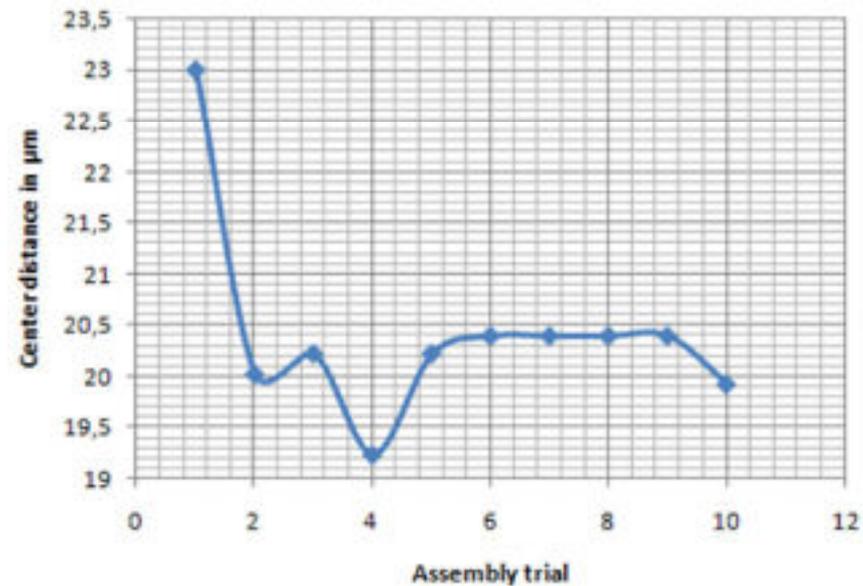
Test pieces outside tolerances, initial plastic deformation but decent repeatability

Conclusions

- K.B. functions are extremely useful tools for 2D periodic structures

- K.B. range of validity is larger than predicted but not enough to cover CLIC region

- A fitting with only one free parameter is under investigation

- K.B. does not consider rounded irises, a possible correction is proposed

- K.B. can be used with good results also for non-periodic structures

- Diameter of the cells (2*B) is the most critical tolerance (1 micron or better) due to phase slip

- For this tolerance the VSWR does not represent a problem

- Bookshelf tolerances can be satisfied by structure in disks; it is critical for structures in quadrants

- Cooling water temperature could require a stabilization @ 0.1 C

- Disk technology (milling) is ready, quadrant is not (machining & assembly)