CLIC drive beam accelerating (DBA) structure

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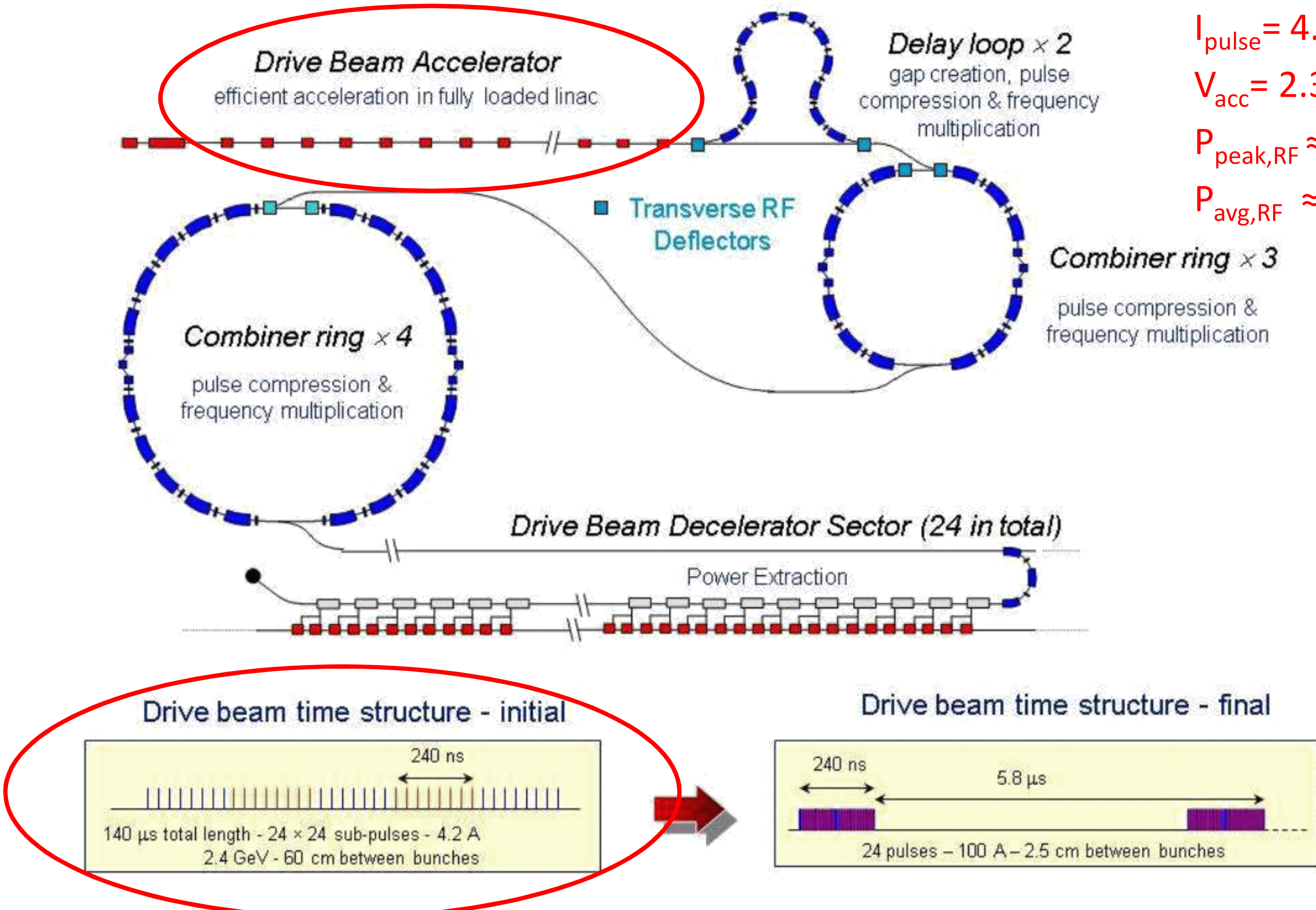
Outline

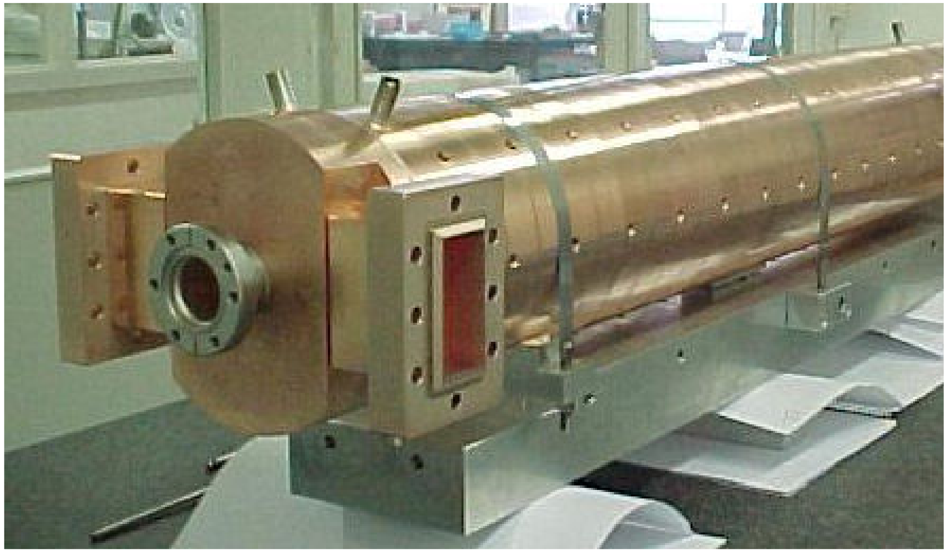
- CLIC drive beam complex,
  3 GHz DBA structure
- design of 1 GHz DBA structure
- optimisations for efficiency and filling time
- damping and detuning
- summary

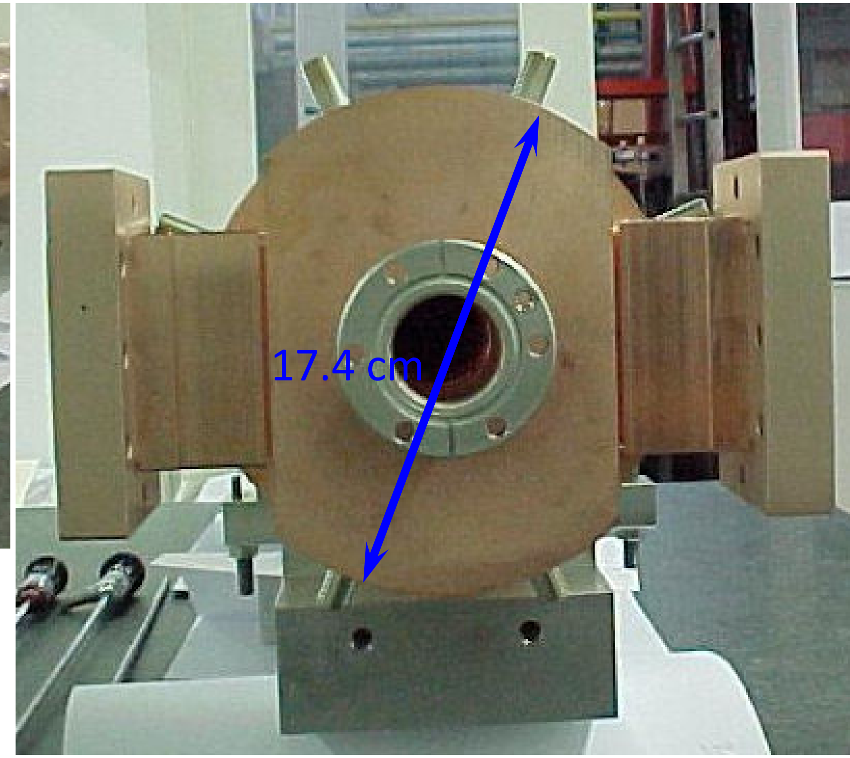
CLIC RF power source

f_{acc}= 0.99952 GHz
I_{pulse}= 4.2 A
V_{acc}= 2.37 GV
$P_{peak,RF} \approx$ 12 GW
$P_{avg,RF} \approx$ 90 MW



3 GHz DBA structure





f_{acc}= 3 GHz

P_{in}= 33 MW

n_{cell}= 33

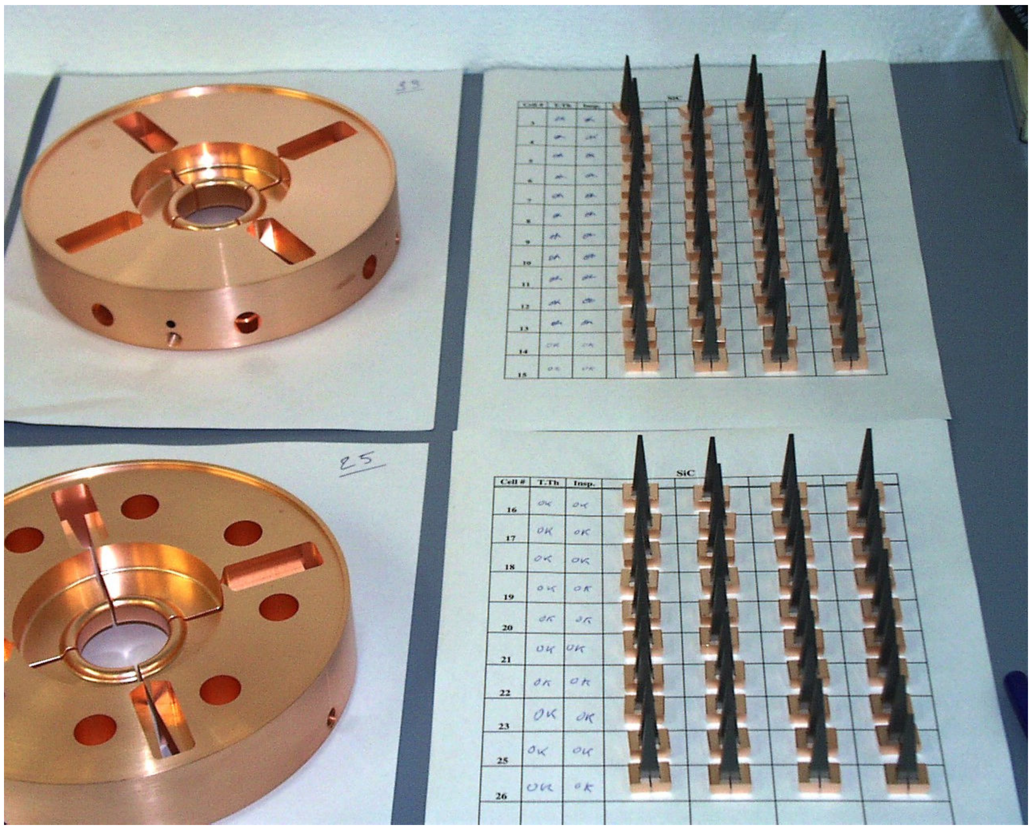
Length= 1.22 m

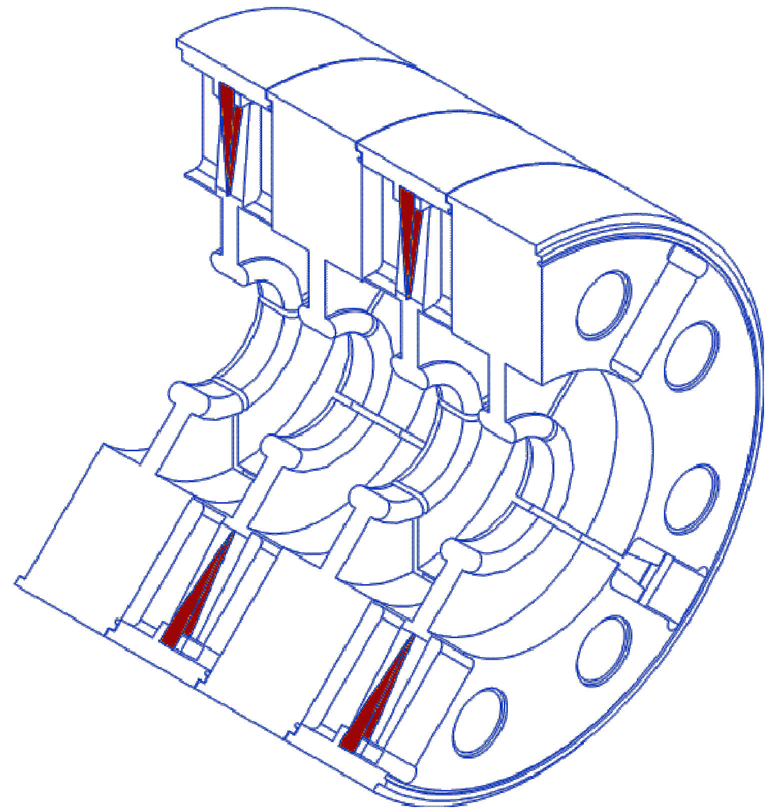
$\emptyset_{outside}$= 17.4 cm

weight ≈ 200 kg

3 GHz DBA structure

SICA = Slotted Iris – Constant Aperture

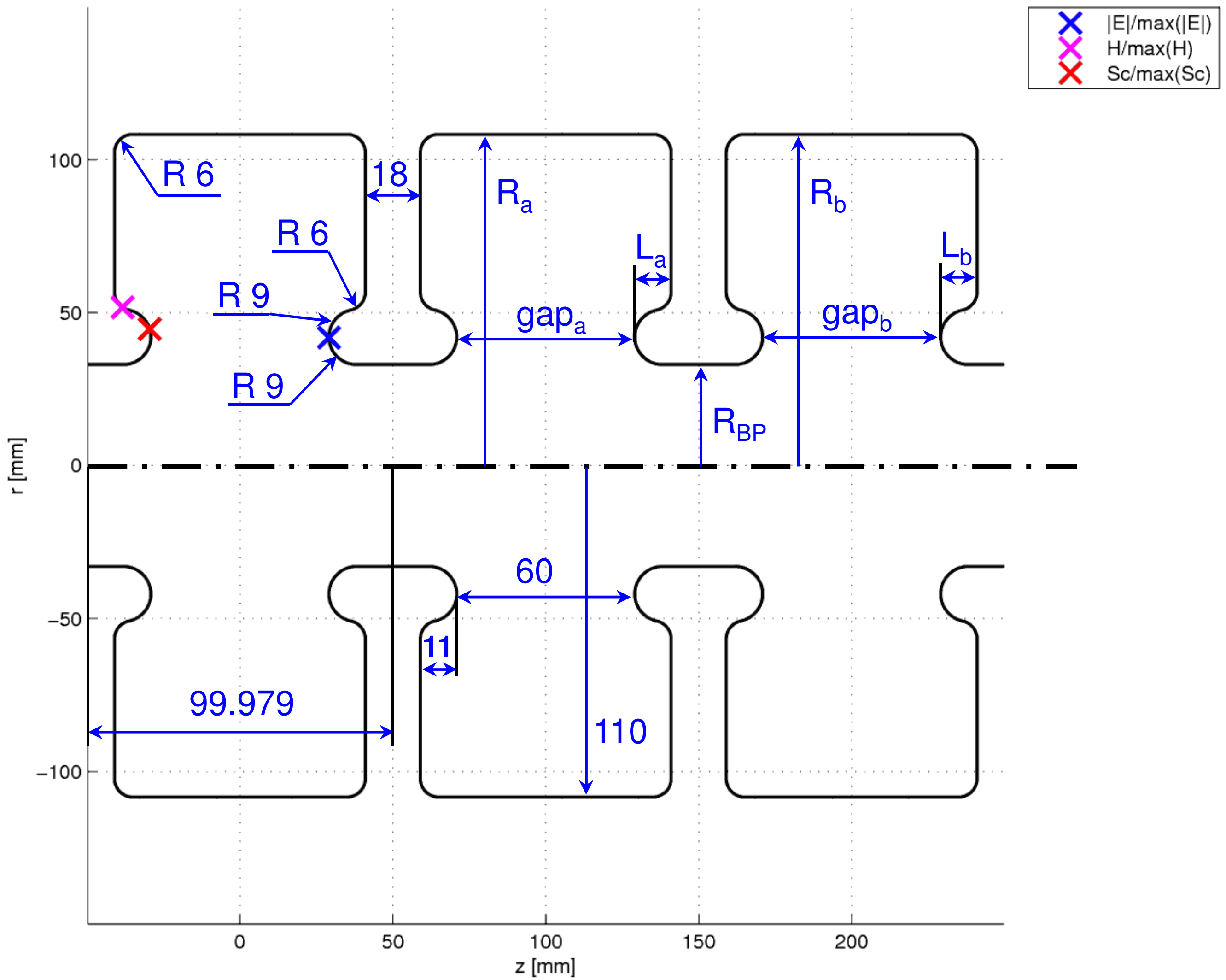




1 GHz DBA structure

- SICA principle
- but no direct scaling possible
  - 3 GHz: Ø= 17.5 cm, L= 1.2 m, weight= 200 kg
    1 GHz: Ø= 52.5 cm, L= 1.2 m, weight= 1800 kg
  - klystron P_{RF} ~ 10 to 15 MW
    (optimising klystron cost per MW and per operating hour and modulator cost)
  - noise, phase error reduction if t_{fill}= 240…250 ns
    (combination scheme => multiplication of phase noise, $t_{DL} \approx$ 245 ns, $t_{CR\ I} \approx$ 2*245 ns, $t_{CR\ II} \approx$ 6*245 ns)

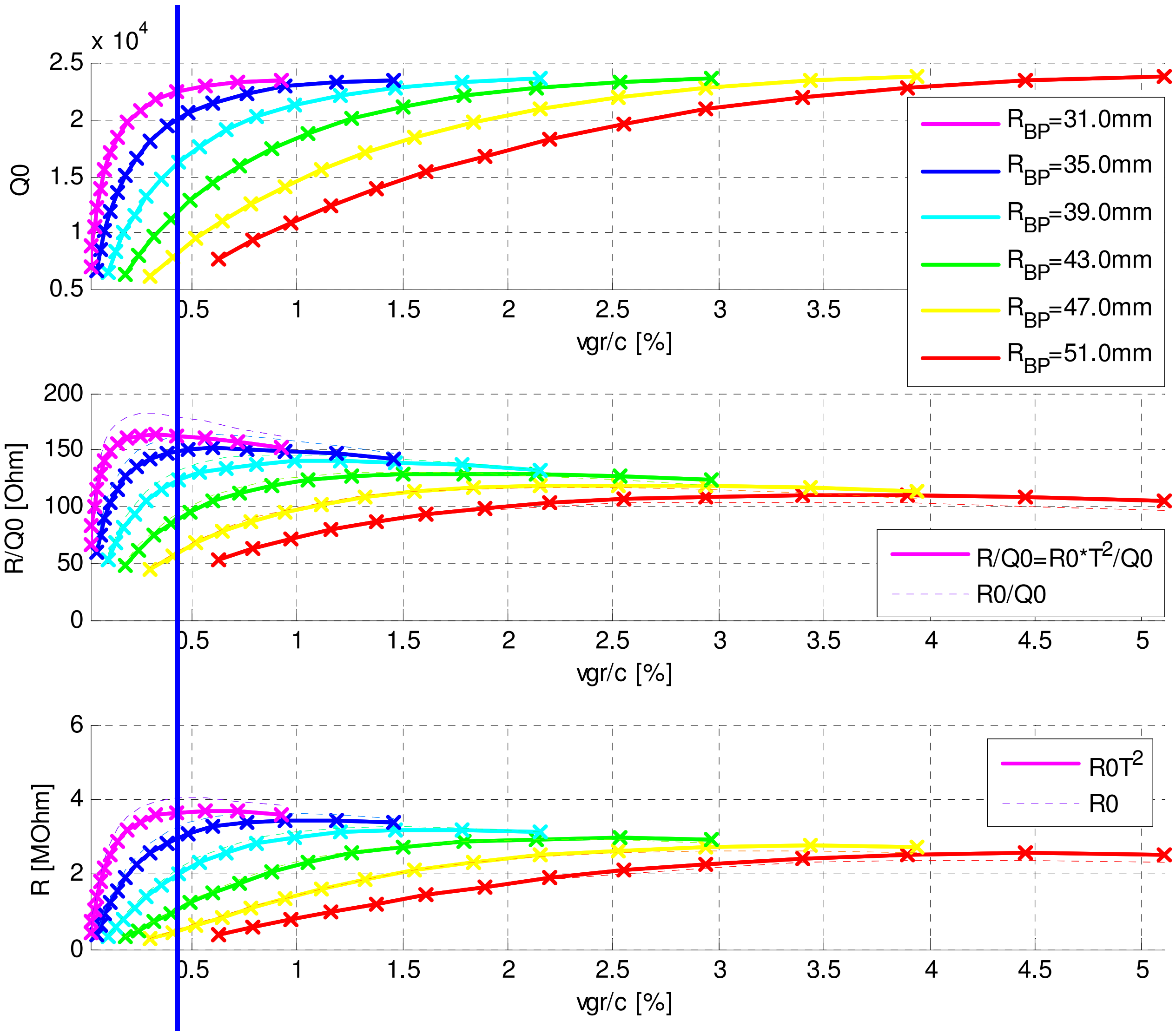
basic cell geometry



3 basic cells

typical dimensions

simulations of basic cells



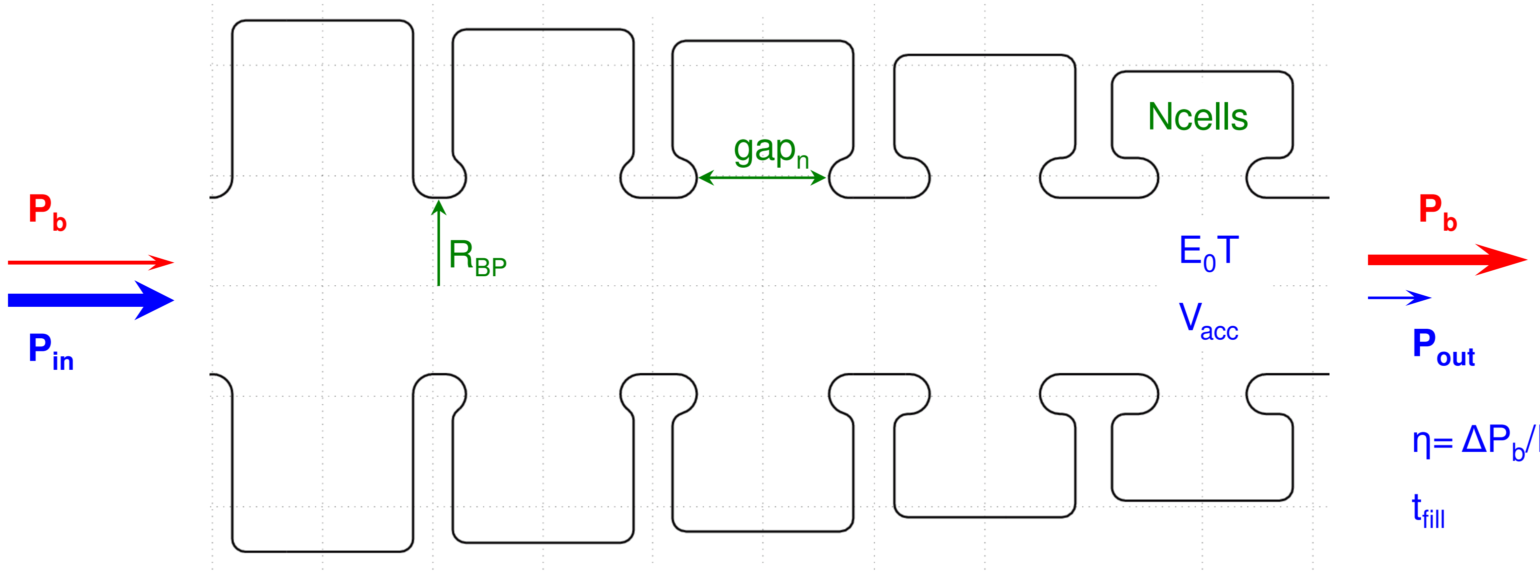
variations:
R_{BP}
gap <=> vgr/c

tuning R_a =>
f_0= 0.99952 GHz

vgr/c range:
min ~ 0.4% to 0.5%

design of TWS

constant aperture

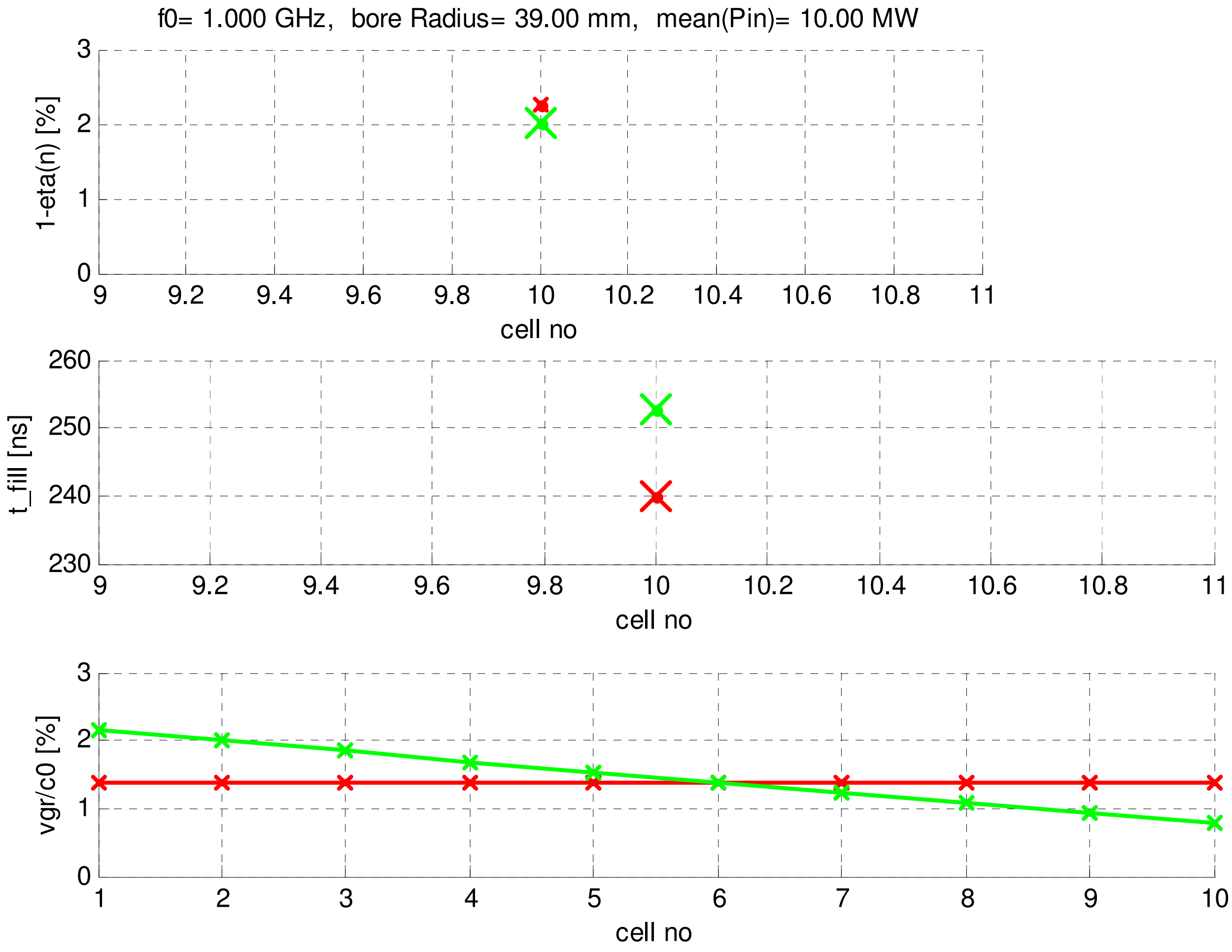


$\eta = \Delta P_b / P_{in}$

t_{fill}

mode spectrum

design of TWS



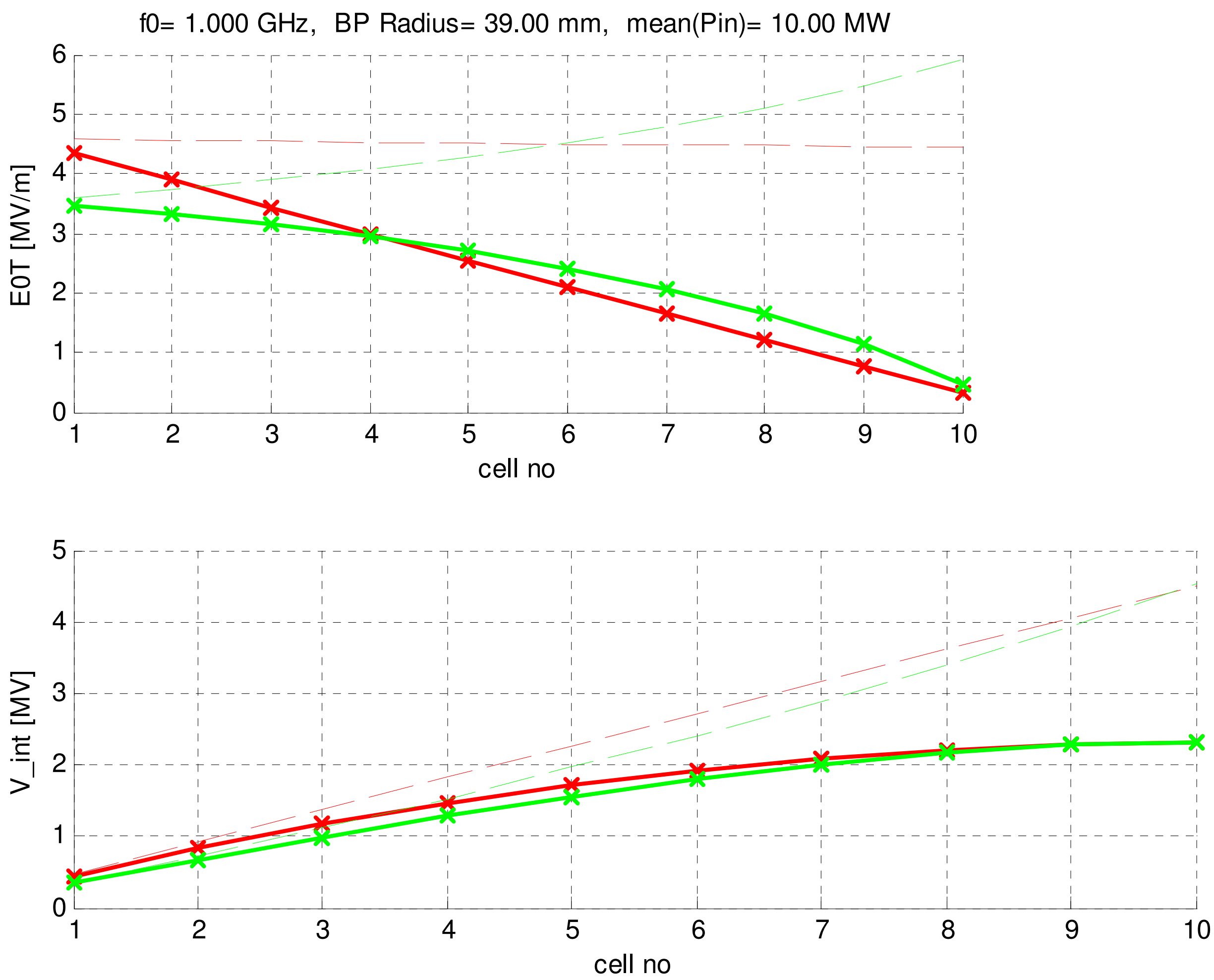
example:

P_{in}= 10 MW
I_b= 4.21 A
N_{cells}= 10
R_{BP}= 39 mm

vgr/c (gap) const
η= 97.7%
$t_{filling}$= 239.9 ns

vgr/c lin. distribution
η= 98.0%
$t_{filling}$= 252.7 ns

design of TWS



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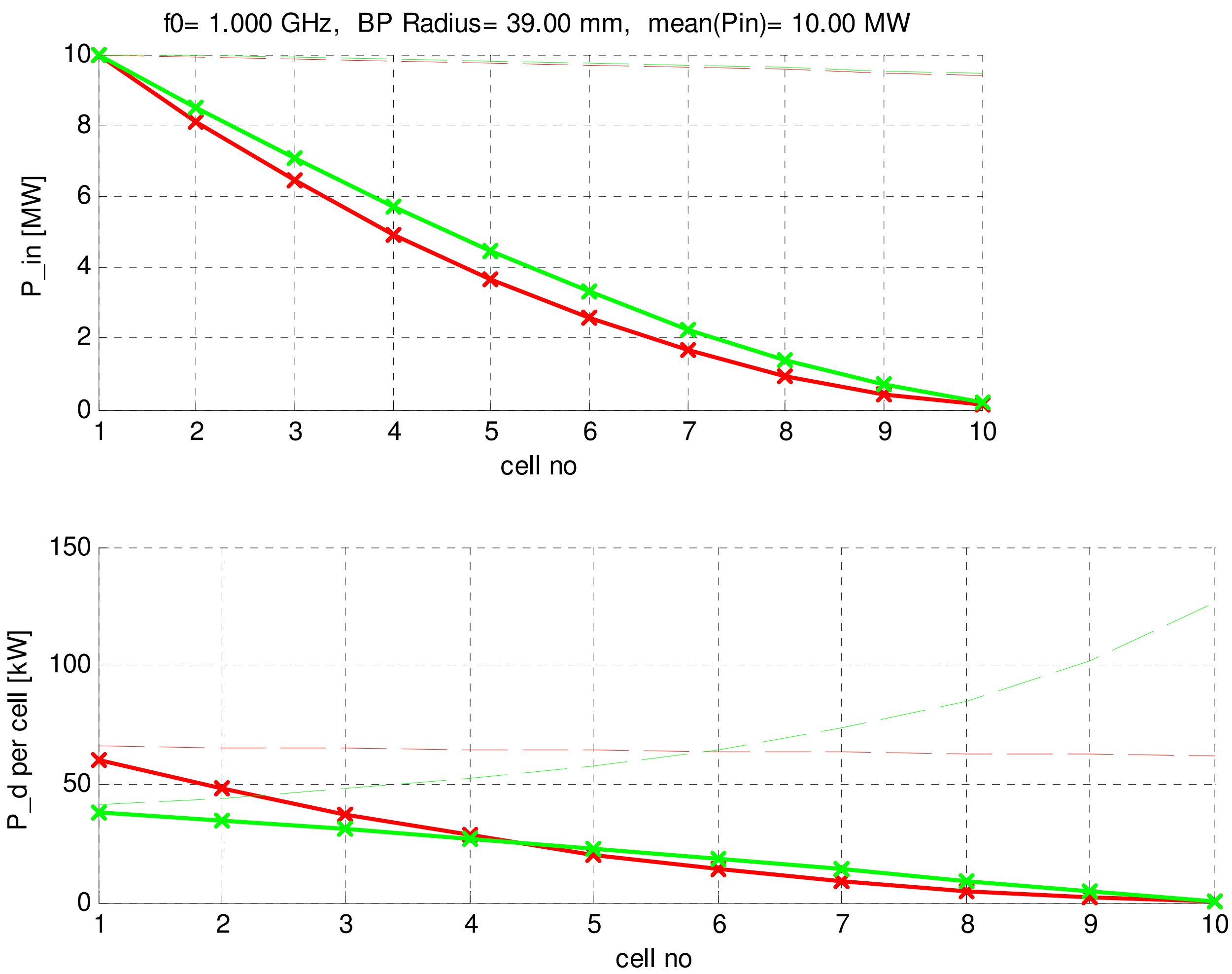

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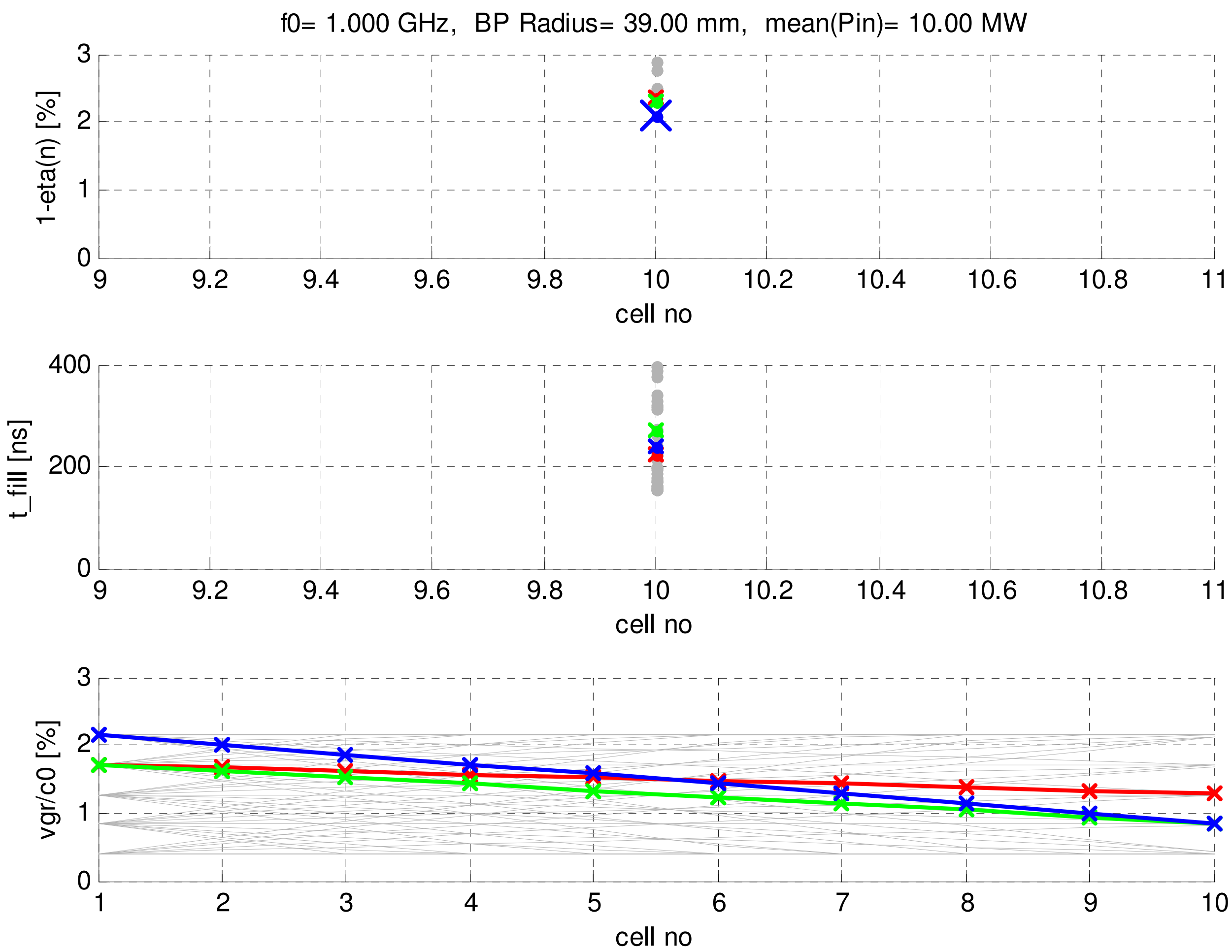
optimisations



P_{in}= 10 MW
I_b= 4.21 A
R_{BP}= 39 mm

Ncells= 10

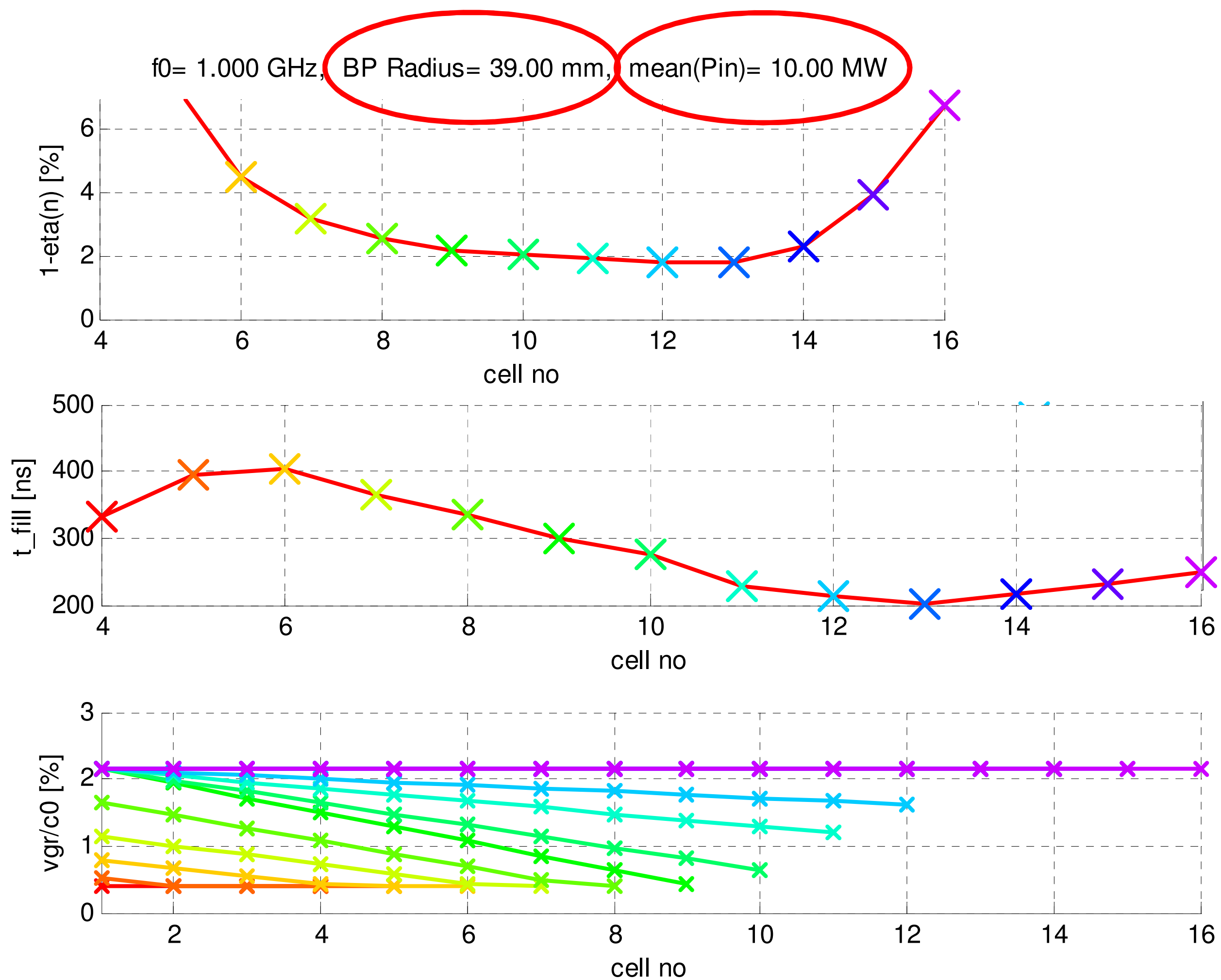
vgr/c lin. distribution

vgr/c= [2.2% to 0.86%]

vgr/c= [1.7% to 0.86%]

vgr/c= [1.7% to 1.28%]

optimisations - efficiency

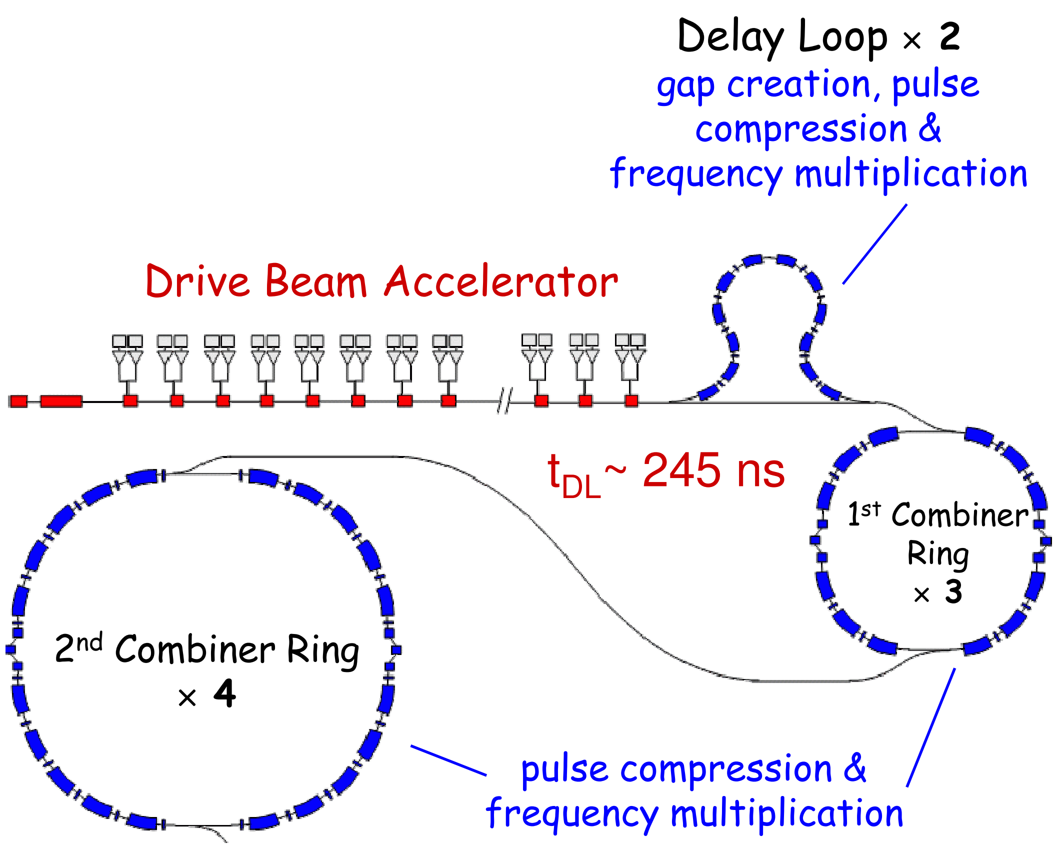


P_{in}= 10 MW
I_b= 4.21 A
R_{BP}= 39 mm

Ncells= 4 .. 16

vgr/c lin. distribution
optimised for
efficiency

combined optimisations

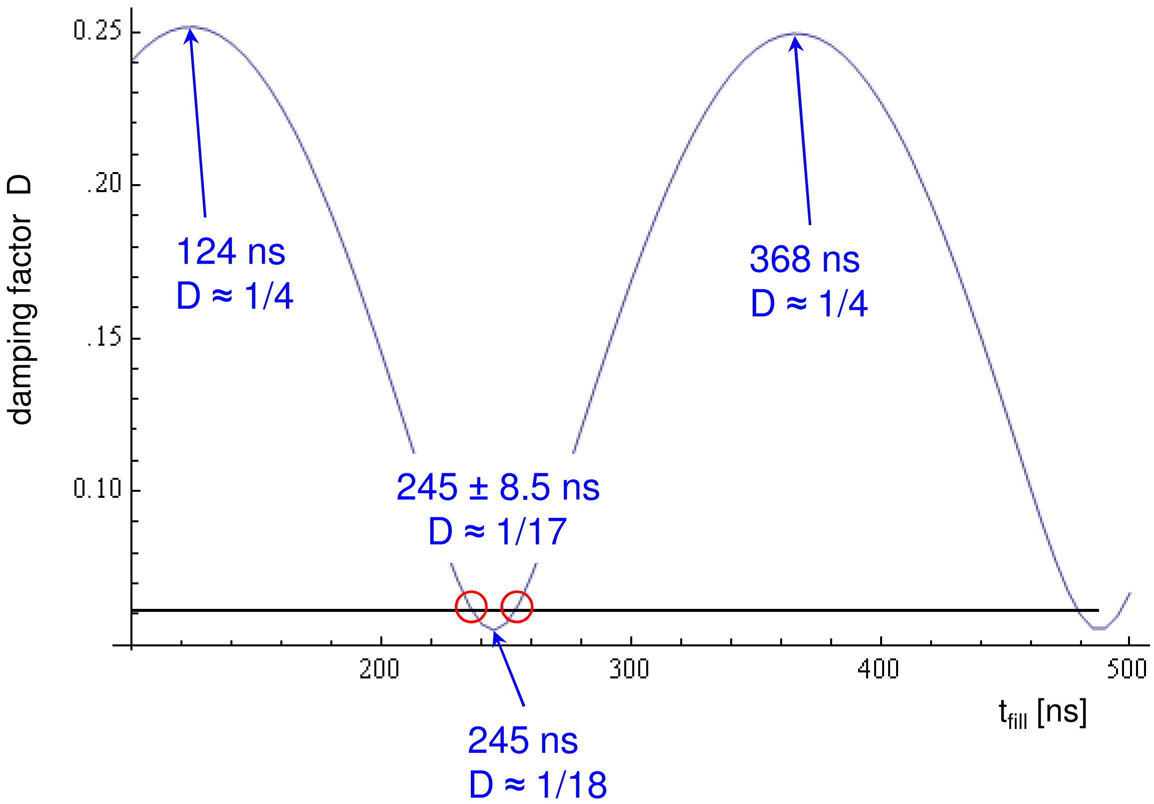


DBA structure tasks:

- acceleration => η_{RF}
- noise damping => D, t_{fill}

appropriate t_{fill} => noise suppression at f = $1/t_{DL}$

combined optimisations



DBA structure tasks:

- acceleration => η_{RF}
- noise damping => D, t_{fill}

appropriate t_{fill} => noise suppression at $f = 1/t_{DL}$

combination for optimisation

$C(\eta_{RF}, t_{fill}) = f_1(\eta_{RF}) + f_2(t_{fill})$

$f_1(\eta_{RF}) = 1 - \eta_{RF}$

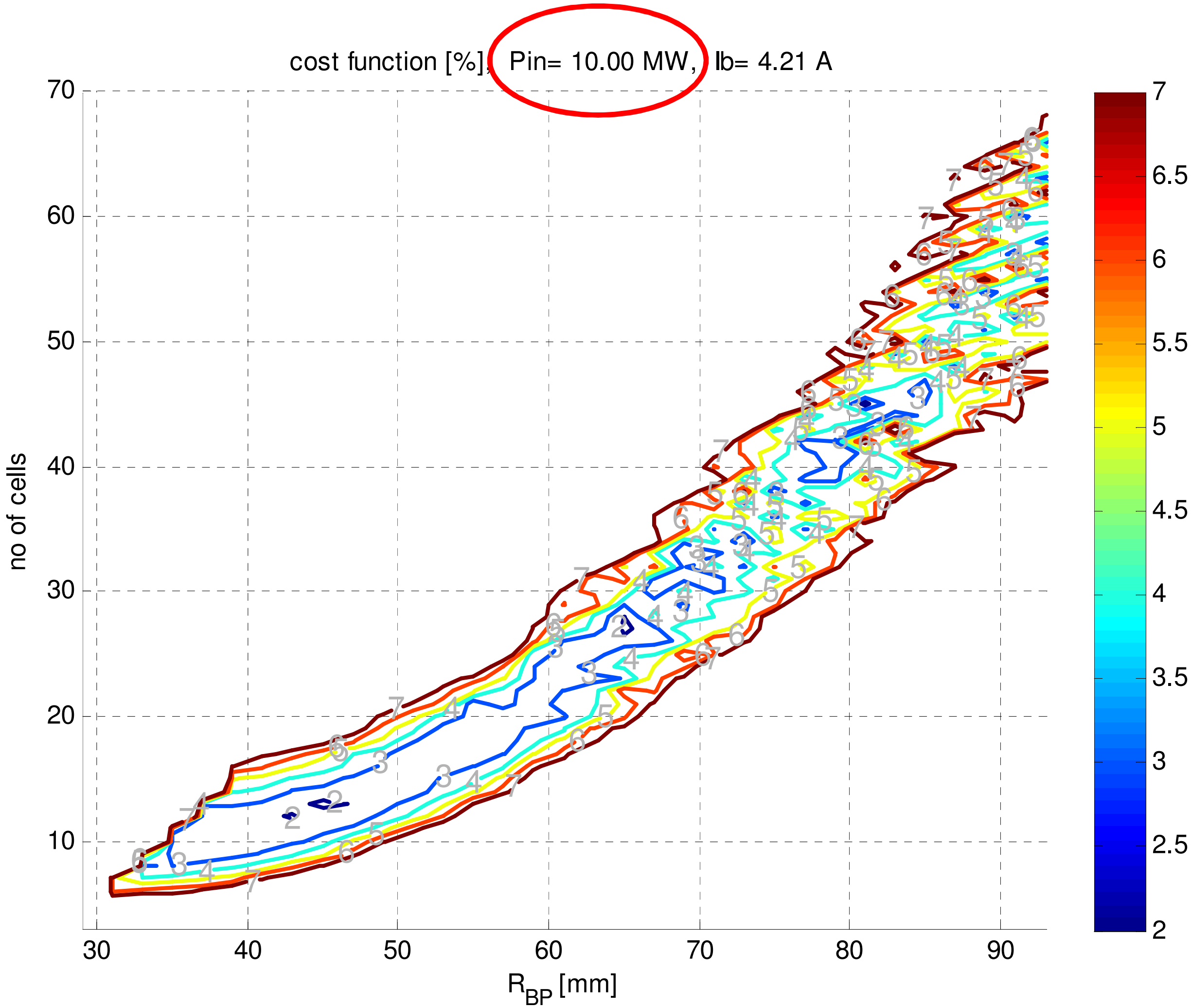
$f_2(t_{fill}) = \alpha \left((t_{fill} - t_0)/\Delta t\right)^2$

$t_0 = 245$ ns

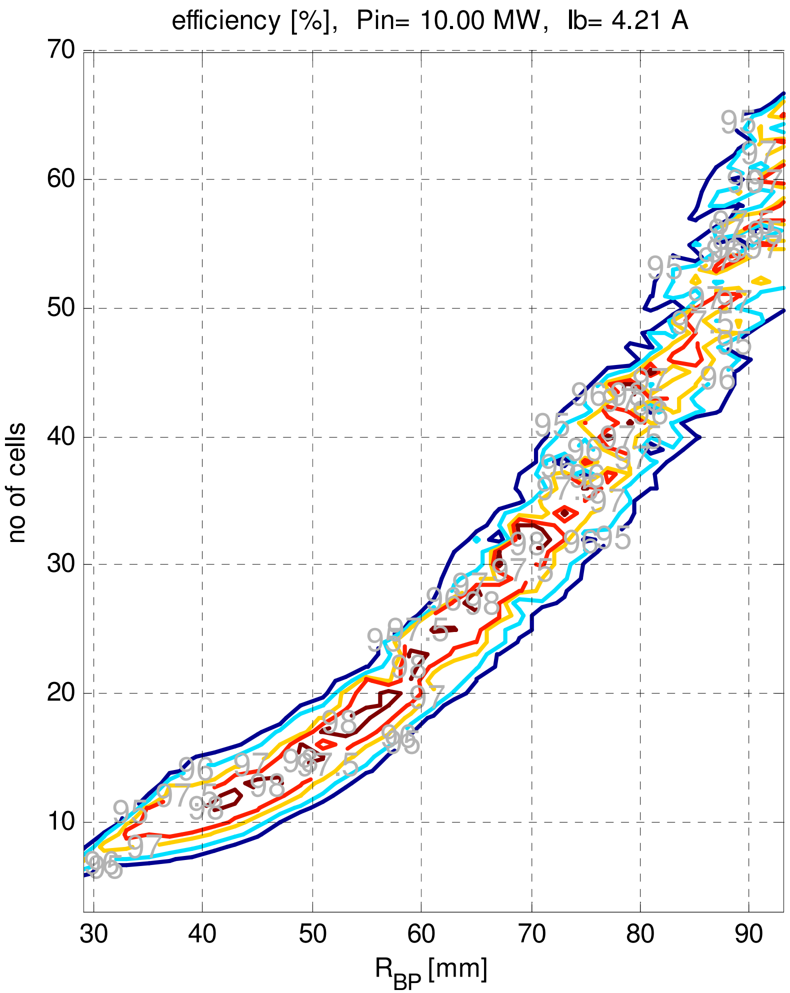
$\Delta t = 8.5$ ns

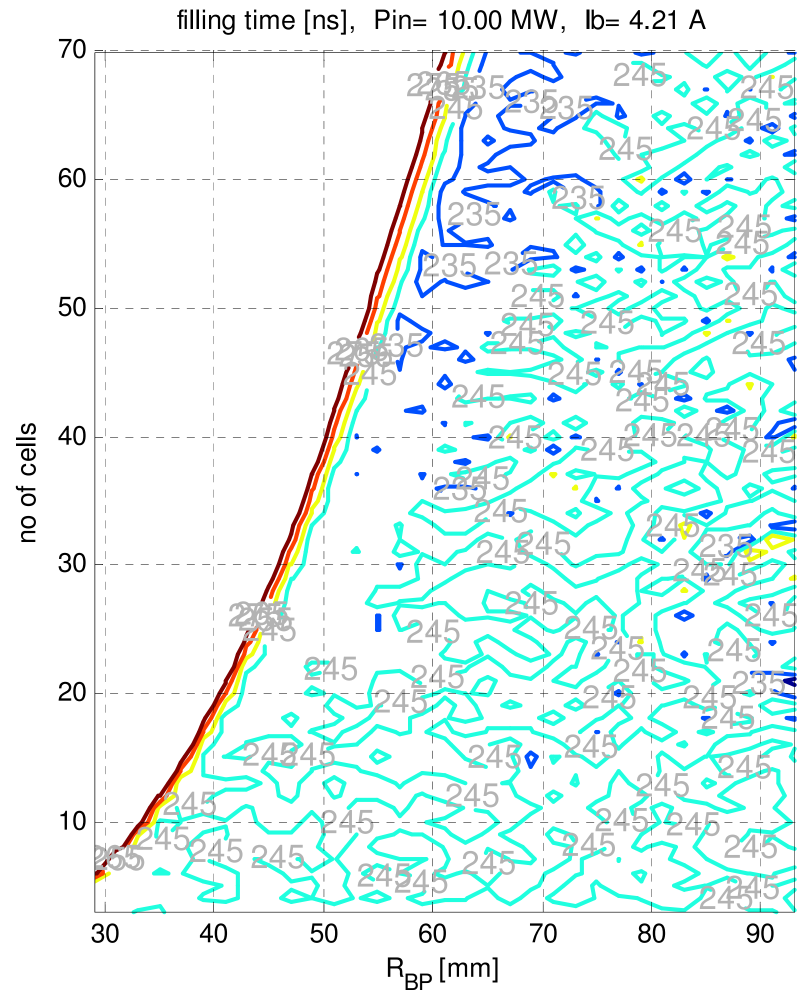
$\alpha = 2\%$

optimisations

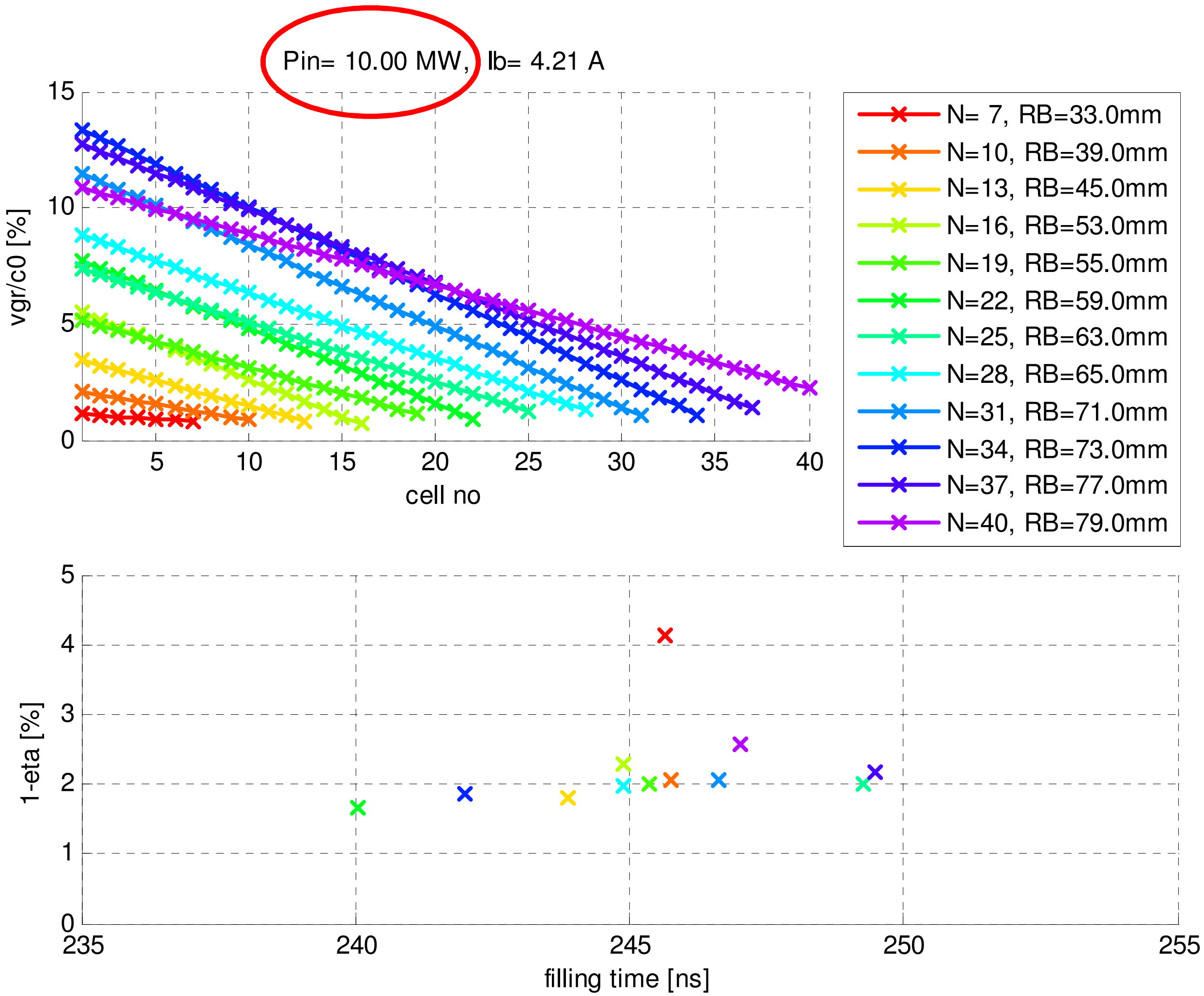


optimisations

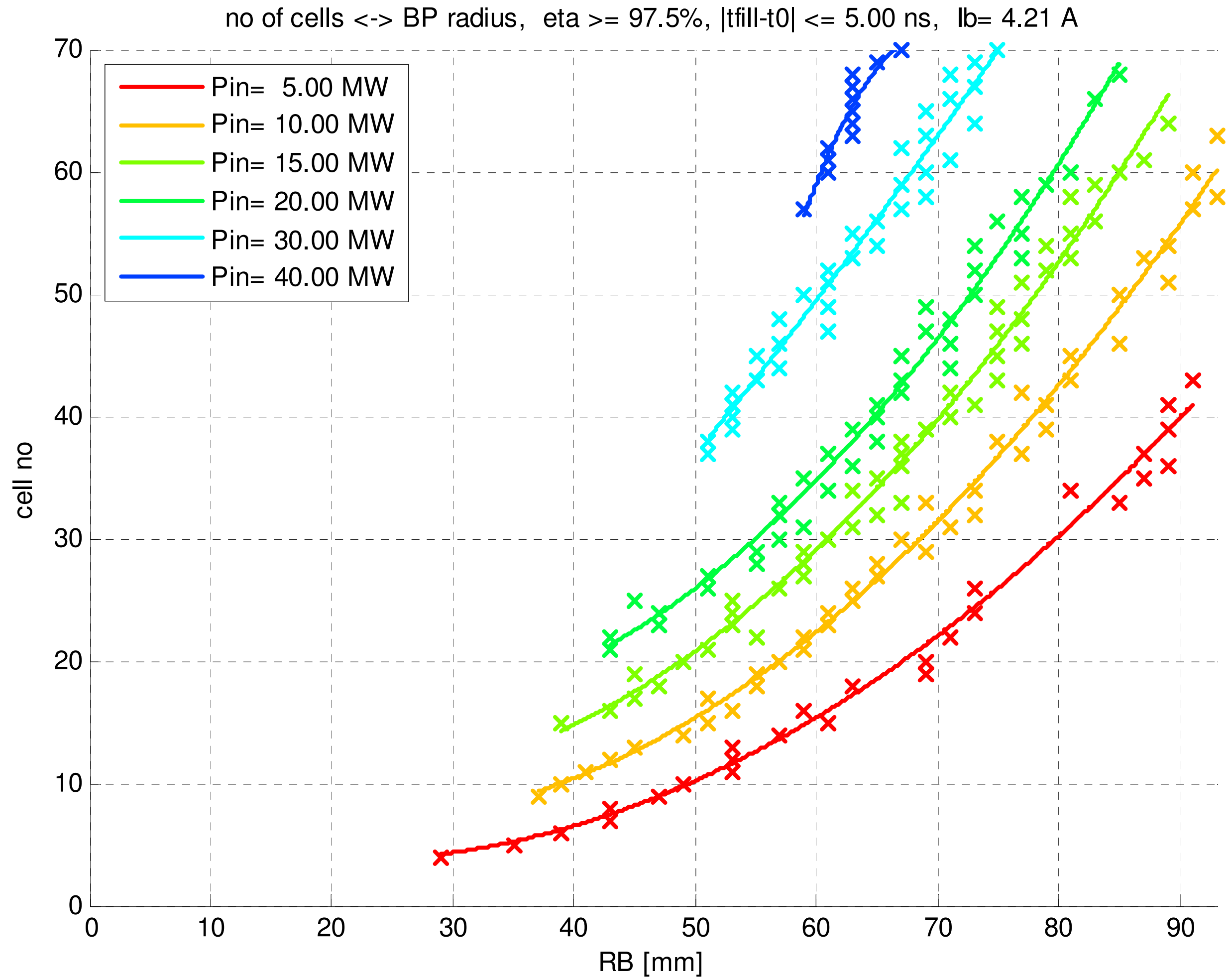




optimisations



optimisations

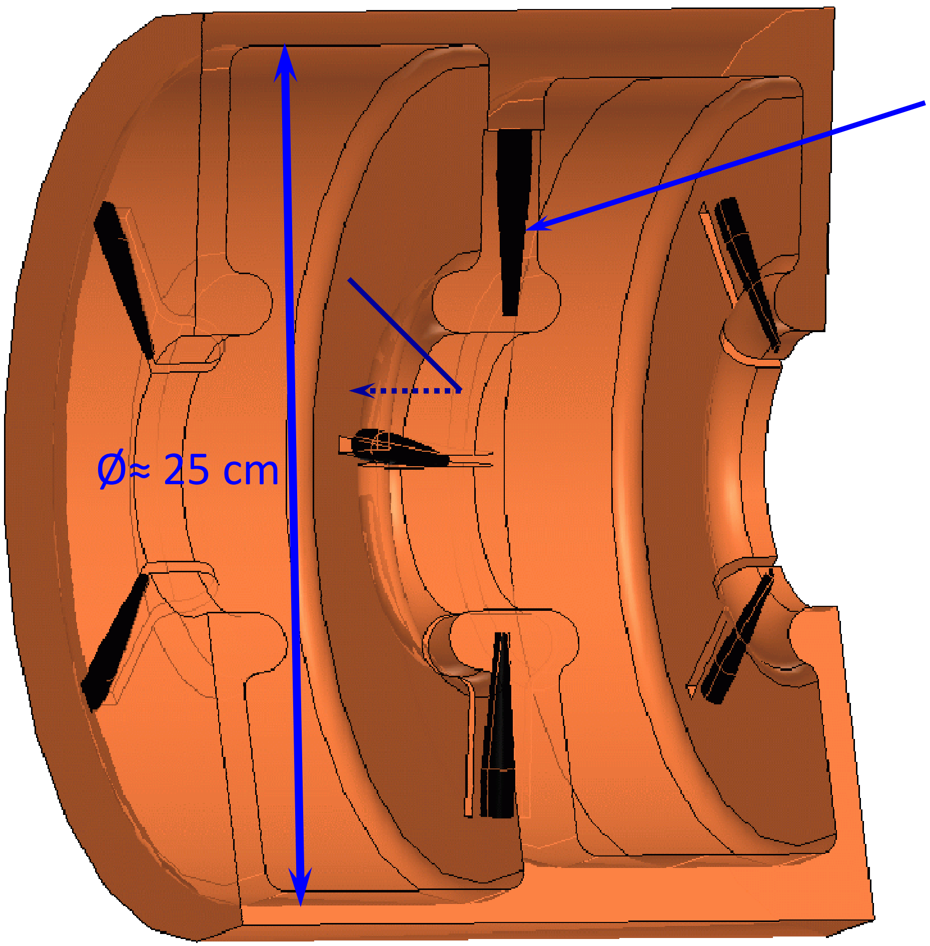


$\eta_{RF} \geq 97.5$ %

$|t_{fill} - 245$ ns$| \leq 5$ ns

damping and detuning

reduction of transverse wakefields by damping and detuning



Alexej Grudiev's suggestion:
dampers in web (~18 mm tick)

acc. mode

$Q_0 = 2.2 \cdot 10^4$, $Q_{ext} = 3.7 \cdot 10^7$

distorted, 0.1° <=> 0.1 mm @ nose

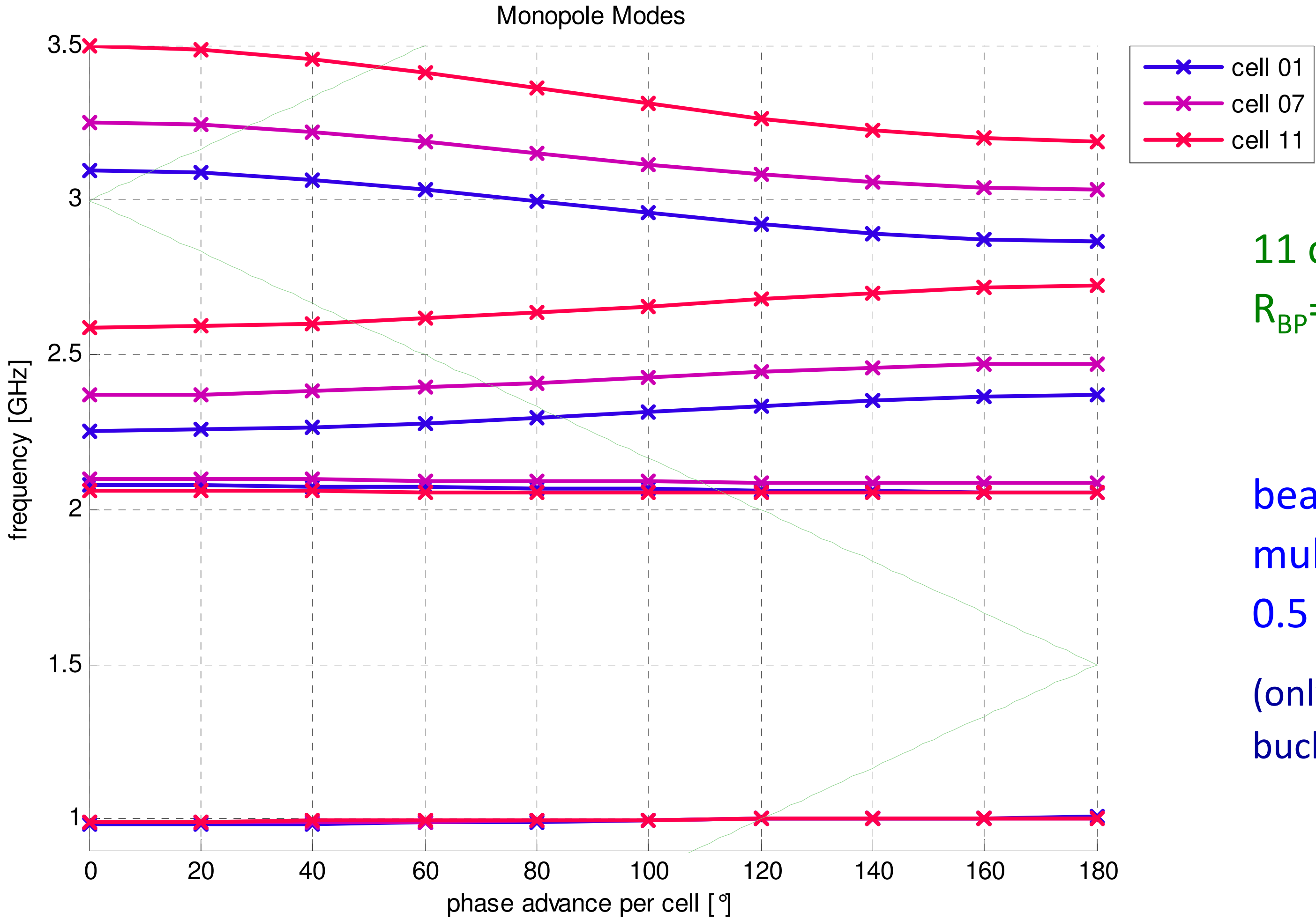
$Q_{ext} = 1.5 \cdot 10^6$

$P_{ext,peak} = 110$ W, $P_{ext,avg} = 0.83$ W

($P_{cell,peak} =$ 30 kW, d.c. 0.75%)

damping and detuning

reduction of transverse wakefields by damping and detuning



11 cell structure

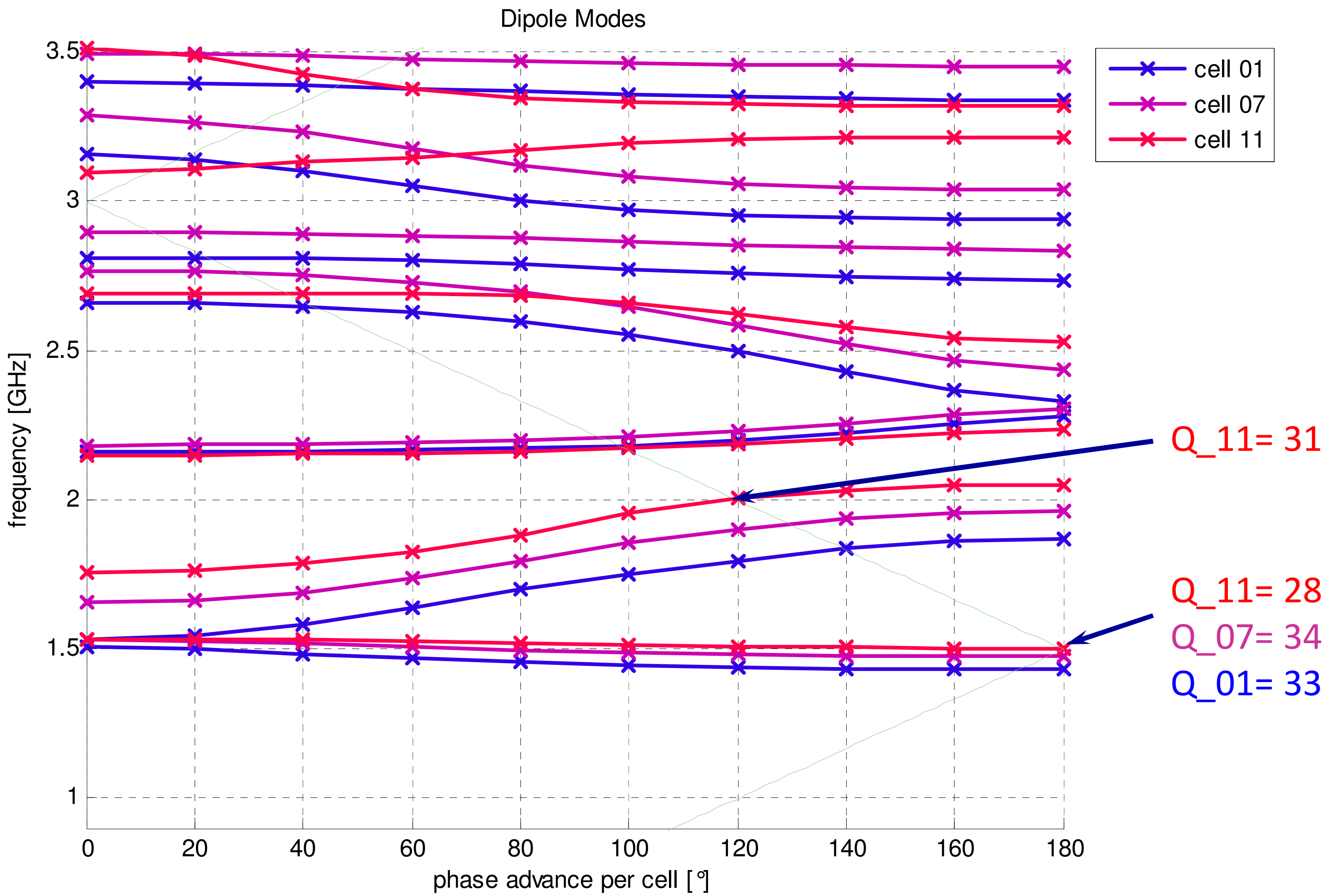
R_{BP}= 41 mm

beam may excite multiples of 0.5 GHz

(only every other bucket filled)

damping and detuning

reduction of transverse wakefields by damping and detuning



next steps

- wakefield calculation
- optimisation of damping
  - RF design
  - beam dynamics
  - mechanical design

=> iterations

summary

travelling wave structure for CLIC DBA

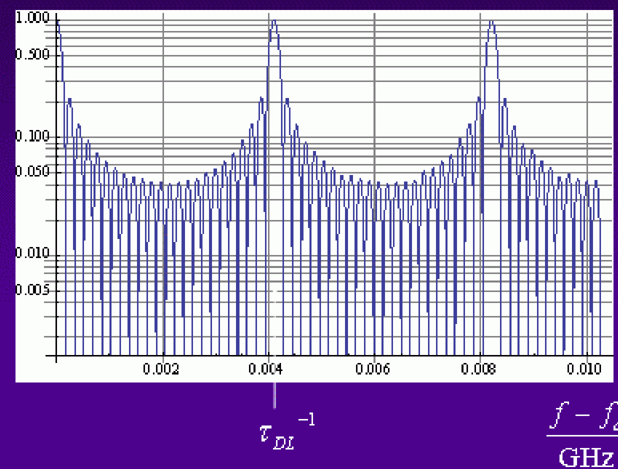
- efficiency ≥ 97%
- filling time 245 ns ± 5 ns
- input RF power 5 to 40 MW
- degree of freedom: no of cells <=> BP radius
- transverse wakefield reduction by detuning and damping
- compact and effective damping

additional slides

Filtering the noise

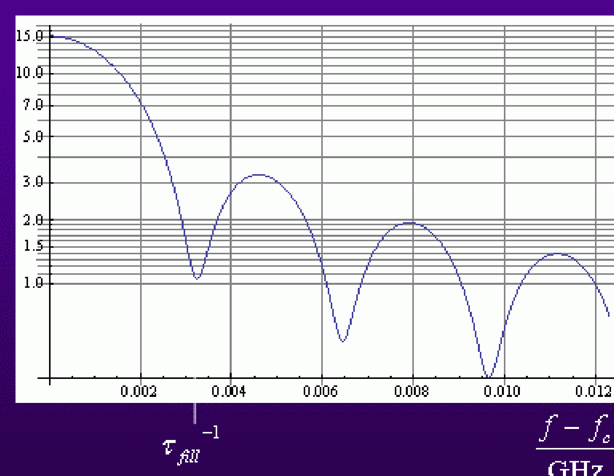
- Much like a recursive filter, the delay loop and the combiner rings filter out certain spectral components of the noise, transfer function:

$$(1+e^{-p\cdot\tau_{DL}})\times(1+e^{-p\cdot\tau_{CR1}}+e^{-2p\cdot\tau_{CR1}})$$
$$\times(1+e^{-p\cdot\tau_{CR2}}+e^{-2p\cdot\tau_{CR2}}+e^{-3p\cdot\tau_{CR2}})$$



- Due to its group delay, also the accelerating structure has a beneficial filtering effect:

- The overall effect is maximized if the structure group delay is made equal to the delay loop length.

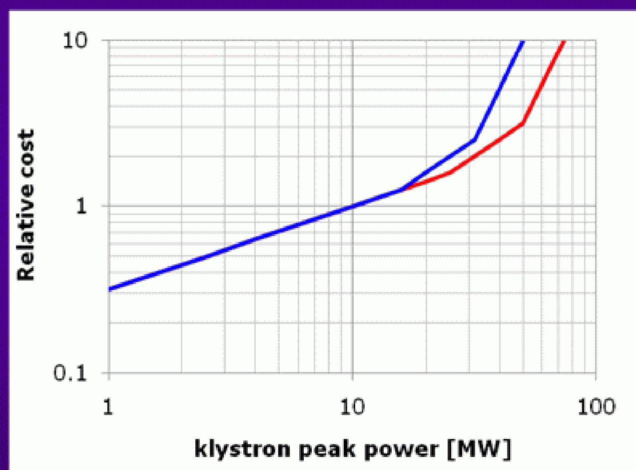


additional slides

Cost scaling of pulsed klystrons?

How does the klystron cost depend on the peak power?

- Probably: cost per klystron proportional to (peak power)$^{1/2}$ (*)
- At a level of around 15 MW peak, the slope will become steeper due to increased system complexity.
- This leads to the following model:



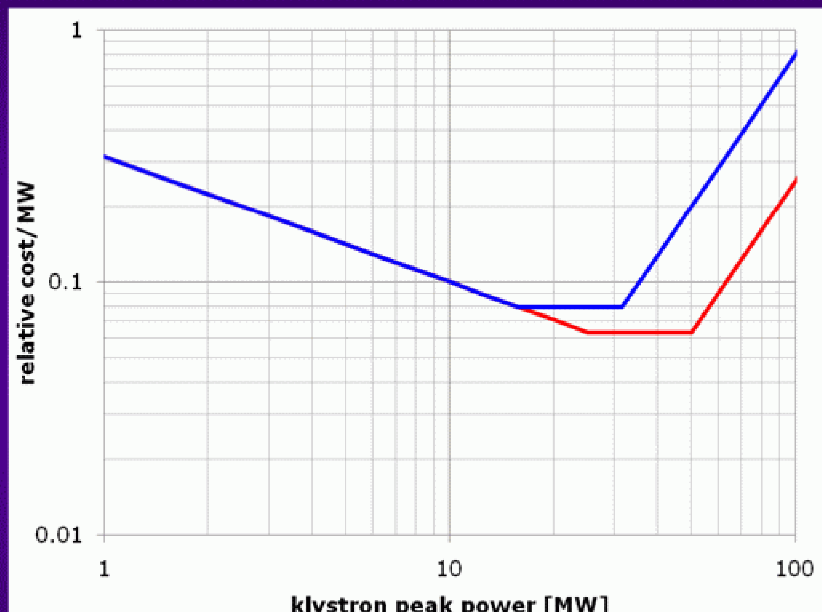
- Blue: present state of the art
- Red: assuming a major investment into the development of a dedicated 30 MW tube

(*) rule of thumb given by T. Habermann/CPI. Rees/LANL estimates $P^{0.2}$ for 0.5 to 5 MW tubes.

additional slides

Cost per MW

- Using the above model, here's the klystron cost per MW (peak)



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additional slides

Considering tube lifetime

- In spite of its price, a klystron is a consumable!
- A klystron has a finite lifetime; this will also depend on its internal complexity (and on the peak power!).
- The lifetime will depend on many parameters, primarily the current density, but here's one estimate ...

MIL-HDBK-217F
NOTICE 1

7.1 TUBES, ALL TYPES EXCEPT TWT AND MAGNETRON

Alternate* Base Failure Rate for Pulsed Klystrons - λ_b

P(MW)	F(GHz) .2	.4	.6	.8	1.0	2.0	4.0	6.0
.01	16	16	16	16	16	16	16	16
.30	16	16	17	17	17	18	20	21
.80	16	17	17	18	18	21	25	30
1.0	17	17	18	18	19	22	28	34
3.0	18	20	21	23	25	34	51	
5.0	19	22	25	28	31	45	75	
8.0	21	25	30	35	40	63	110	
10	22	28	34	40	45	75		
25	31	45	60	75	90	160		

λ_b = 2.94 (F)(P) + 16

F = Operating Frequency in GHz, $0.2 \le F \le 6$

P = Peak Output Power in MW, $.01 \le P \le 25$ and $P \le 490\ F^{-2.95}$

*See previous page for other Klystron Base Failure Rates.

Learning Factor - π_L

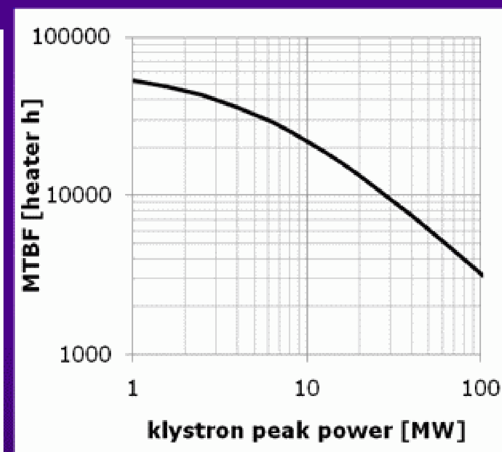
T (years)	π_L
≤ 1	10
2	2.3
≥ 3	1.0

$\pi_L = 10(T)^{-2.1}$, $1 \le T \le 3$
$= 10$, $T \le 1$
$= 1$, $T \ge 3$

T = Number of Years since Introduction to Field Use

Environment Factor - π_E

Environment	π_E
G_B	50

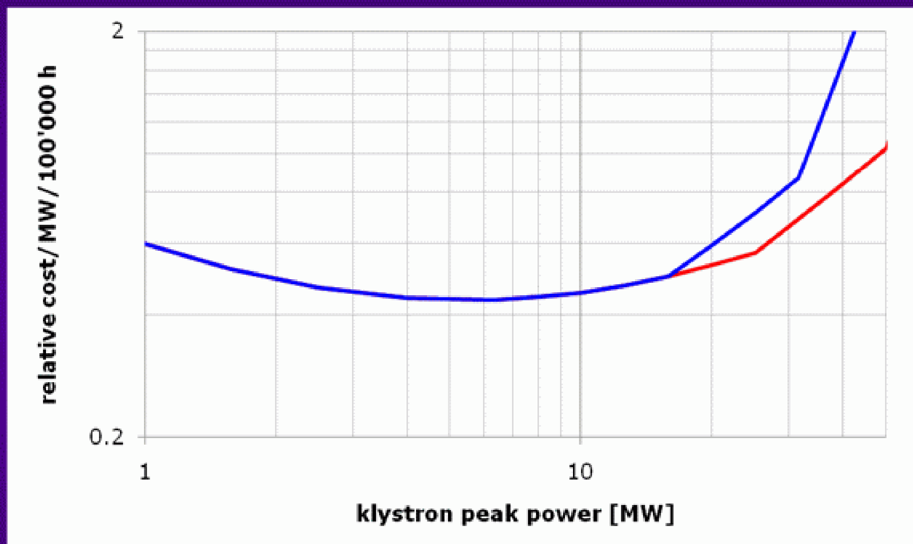


What about an MBK?: is the tube dead if one of *n* beams fails? If the design is good, the *n* beams would fail at around the same time ...

additional slides

Cost per MWh

- Even if this model may be wrong, there will be a cost per MW and per operating hour: With the above model, this becomes:



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