CLIC Drive Beam Linac

Rolf Wegner

Outline

- Introduction: CLIC Drive Beam Concept
- Drive Beam Modules (modulator, klystron, accelerating structure)
- Optimisation of accelerating structure
- Conclusions

Introduction: CLIC Drive Beam

The CLIC Drive Beams are powerful energy sources from which the Power Extraction and Transfer Structures (PETS) extract a total peak power of 9.2 TW at X-band (3 TeV CLIC)

- Specs: 2.4 GV, 100 A, 24 x 240 ns long bunch trains, bunch spacing <=> 12 GHz, 50 Hz rep. rate
- 2 x 24 x 240 GW peak, 140 MW avg beam power
  60 kJ / bunch train, 1.4 MJ / pulse

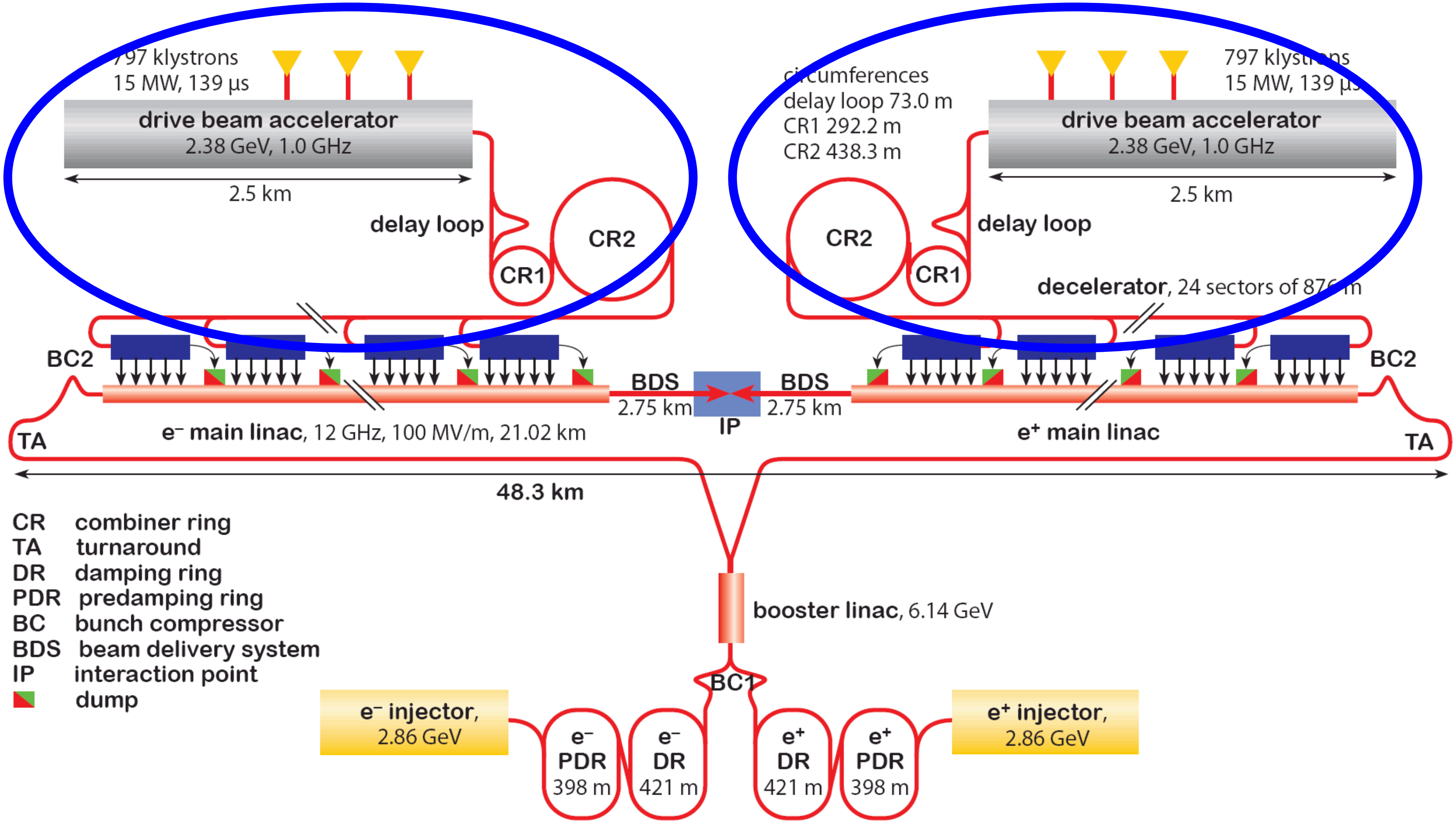
Reason: efficient X-band power production

(alternative: 35'000 x 50 MW X-band klystrons + pulse compr.)

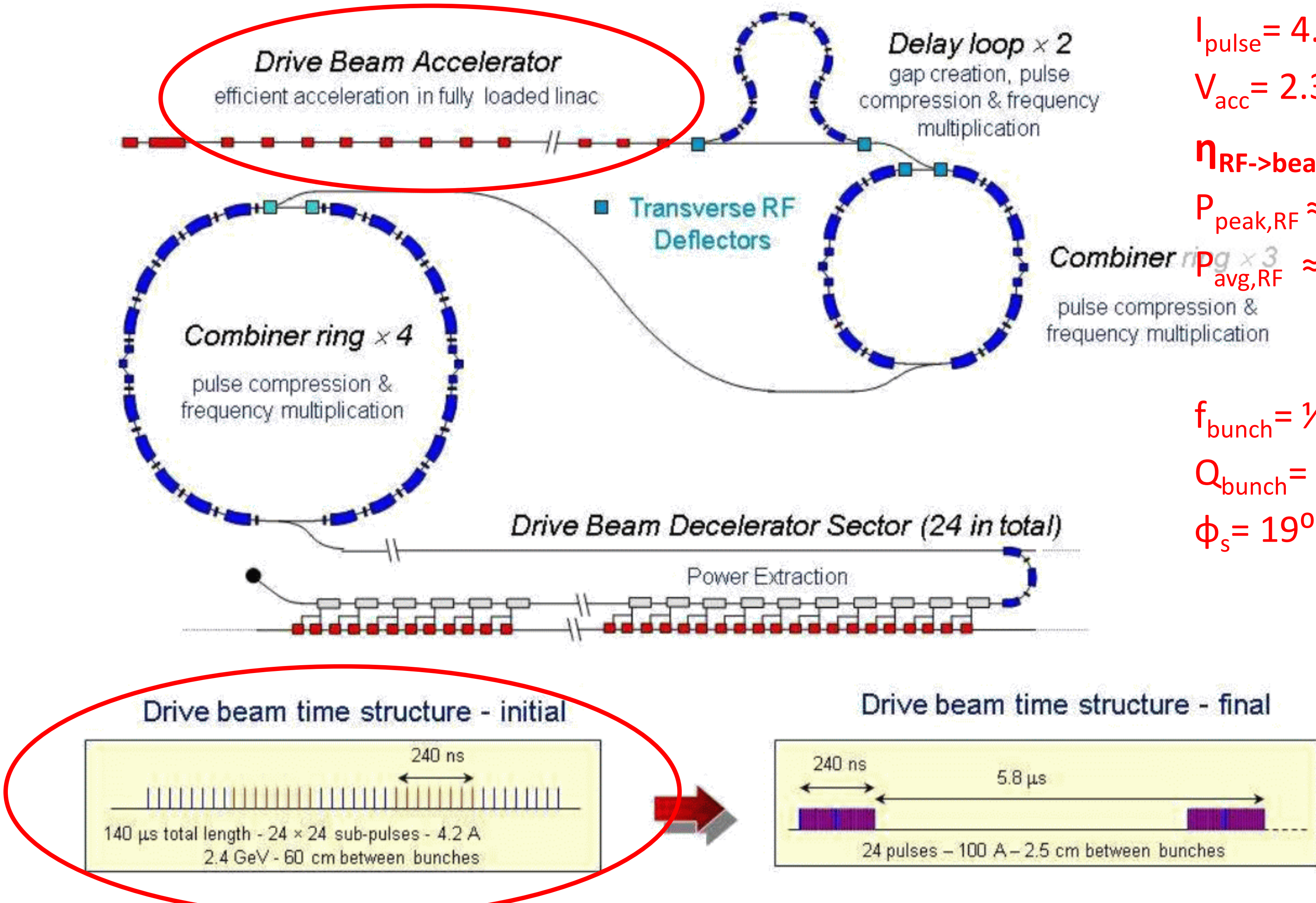
Introduction: CLIC Drive Beam

Stage	f_{bunch}	f_{acc}	$I_{beam,\ train\ avg}$	V_{beam}	T_{train}
DB source					
SH bunchers	500 MHz				
DB acceleration		1 GHz	4.2 A	2.4 GV	140 µs
beam gymnastics	↓		↓		↓
	12 GHz		100 A	2.4 GV	24 x 240 ns
PETS					
main beam acc. structures		12 GHz			

Introduction: 3 TeV CLIC scheme



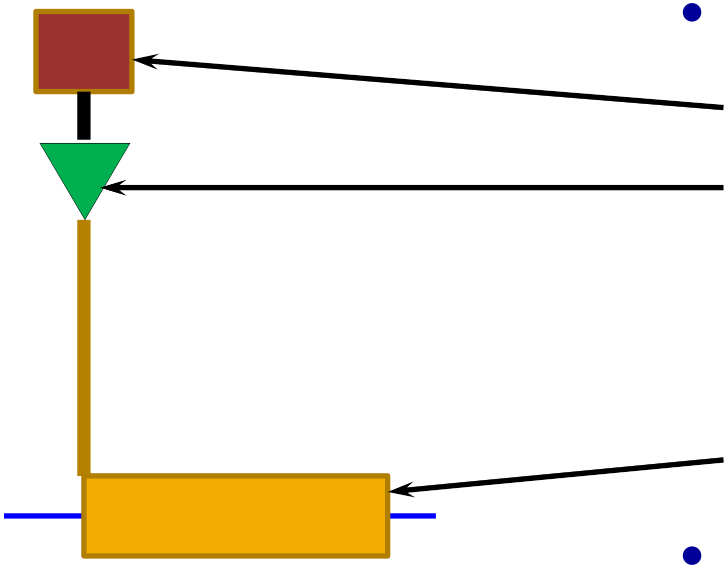
Introduction: CLIC Drive Beam Complex



f_{acc}= 0.99952 GHz
I_{pulse}= 4.2 A
V_{acc}= 2.37 GV
$\eta_{RF\text{->}beam} \geq$ 95%
$P_{peak,RF} \approx$ 12 GW
$P_{avg,RF} \approx$ 90 MW

f_{bunch}= ½ f_{acc}
Q_{bunch}= 8.4 nC
ϕ_s= 19°

Drive Beam Accelerator



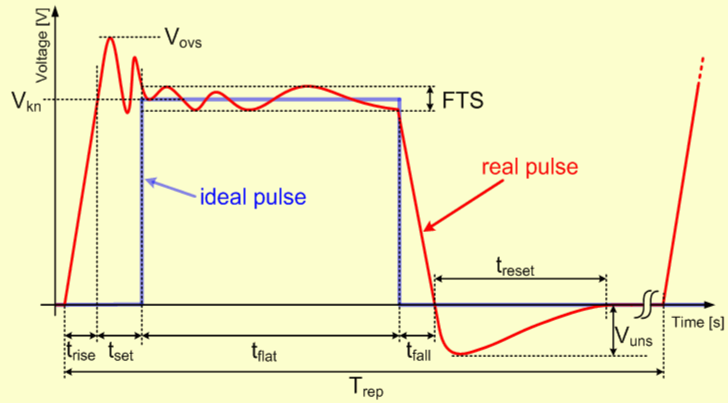
present baseline:

- modules composed of
  modulator (24 MW),
  klystron (1 GHz, 18 MW),
  Erk Jensen: cost optimum 15-20 MW
  including lifetime + future R&D
  accelerating structure (15 MW)
- ~ 1’600 modules for 2 DB-Linacs
  for a 3 TeV CLIC
  $V_{acc,\ module}$= 3.2 MV (φ_s=-19°)

Modulator

CLIC studies & klystron modulators specs

Modulator main specifications			
Pulse voltage	V_{kn}	150	kV
Pulse current	I_{kn}	160	A
Peak power	P_{out}	24	MW
Rise & fall times	**t_{rise}**	**3**	**μs**
Flat-top lenght	t_{flat}	140	μs
Repetition rate	Rep_r	50	Hz
Flat-top stability	FTS	0.85	%
Pulse reproducibility	**PPR**	**10**	**ppm**



avg. power per modulator ~ 180 kW
avg. power of 1’600 modulators ~ 300 MW

Pulse efficiency definition $$\eta_{pulse} = \frac{E_{ideal\_p}}{E_{real\_p}}$$

Approach:
Develop and explore with collaboration partners technologies to meet the ultimate specification for CLIC with the goal to have two working prototypes in 2015-2016.
First collaboration with ETH Zürich started, prototype in 2015

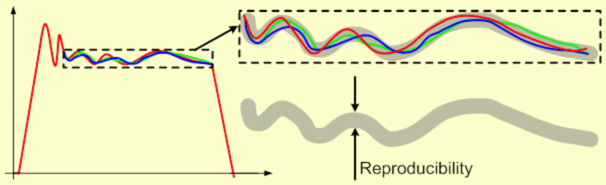
Steffen Döbert: “Plans for the drive beam front-end and CLIC zero outlook”, LCWS 2012

Modulator challenges

CLIC studies & klystron modulators specs

Technology challenges

Pulse to pulse reproducibility:
10 to 100ppm



Modulator and voltage measurement reproducibility **never achieved before**!

AC power quality optimization
More than 1600 modulators pulsing synchronously! Utility grid power fluctuation minimized (~1%) – tough charger design

Machine availability
With more than 1600 modulators, reliability, modularity & redundancy must be optimized for maximum accelerator availability

Modulator topology selection considering:
- Efficiency maximization (max. power limited)
- Reproducibility
- Constant power consumption
- Satisfactory accelerator availability

Need for a global approach! Different solutions must be explored (transformer based, fully solid state, HV & LV solutions)

CLIC Drive Beam klystron modulators R&D strategy

Steffen Döbert: "Plans for the drive beam front-end and CLIC zero outlook", LCWS 2012

Klystron

Klystron specifications

TH1802, ILC MBK klystron

FREQ	Vklystron	Iklystron	V pulse width	RF pulse width	Peak RF Power	Repetition rate	Average Power	Gain	Efficiency	Waveguide
MHz	kV	A	µs	µs	MW	Hz	kW	dB	%	
1300	115	132	1700	1500	10	10	150	47	65	WR 650

CLIC DB klystron design goal, ~ 150kV voltage was assumed for time being

FREQ	Vklystron	Iklystron	V pulse width	RF pulse width	Peak RF Power	Repetition rate	Average Power	Gain	Efficiency	Waveguide
MHz	kV	A	µs	µs	MW	Hz	kW	dB	%	
999.52				150	15-20	50	113		70	

Steffen Döbert: "Plans for the drive beam front-end and CLIC zero outlook", LCWS 2012

Klystron

Tentative klystron parameters

PARAMETER	VALUE	UNITS
RF Frequency	999.5	MHz
Bandwidth at -1dB	tbd	MHz
RF Power:		
Peak Power	≥ 18	MW
Average Power	135	kW
RF Pulse width (at -3dB)	150	µs
HV pulse width (at full width half height)	165	µs
Repetition Rate	50	Hz
High Voltage applied to the cathode	tbd, 150 (max)	kV
Tolerable peak reverse voltage	tbd	kV
Efficiency at peak power	≥ 65	%
RF gain at peak power	tbd, > 50 ?	dB
Perveance	tbd	$\mu A/V^{1.5}$
Stability of RF output signal		
0.5-1.0 of max. power and 0.75 -1.0 of max. cathode HV to be:		
RF input vs output phase jitter [*]	±0.5 (max)	RF deg
RF amplitude jitter	±1 (max)	%
Pulse failures (arcs etc.) during 14 hour continuous test period	≤ 1	
Matching load, fundamental and 2nd harmonic	tbd	vswr
Radiation at 0.1m distance from klystron	≤ 1	µSv/h
Output waveguide type	WR975	

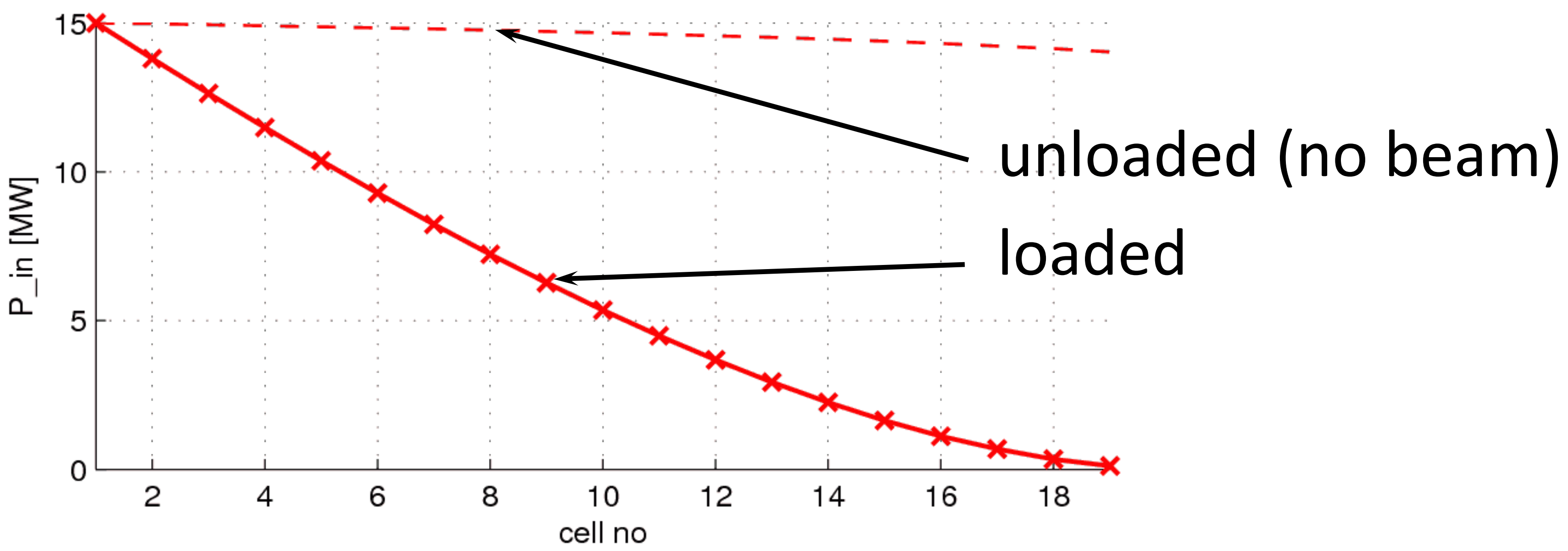
Steffen Döbert: "Plans for the drive beam front-end and CLIC zero outlook", LCWS 2012

Accelerating structure

Fundamental principles:

- full beam loading (RF to beam efficiency ≥ 95%)
- TWS - SICA (Slotted Iris – Constant Aperture)
  (+ short range wakefields, efficient HOM damping)
- filtering of frequencies ~ 4.1 MHz (<=> $T_{combination}$)
  (+ noise reduction <=> combination scheme)
- reduction of wakefields by damping and detuning

Principle: full beam loading



input power at acc. structure: 15 MW (peak)

dissipated power: 330 kW (peak)

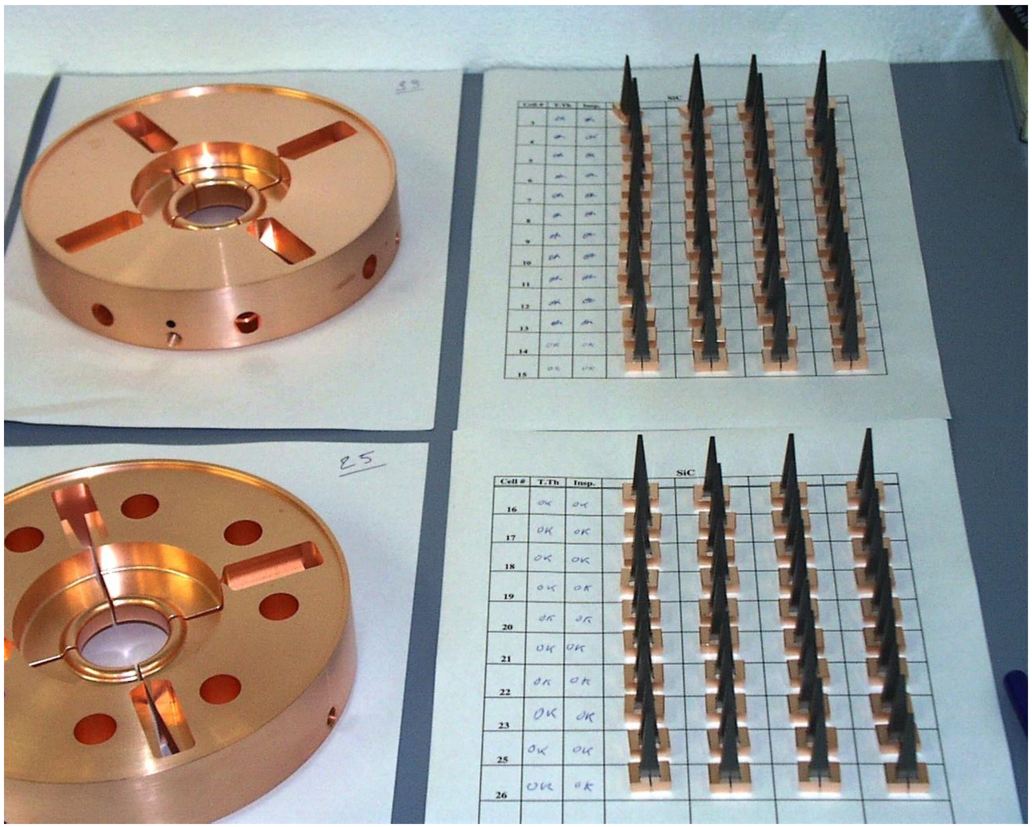
lost power at output: 10 kW (peak)

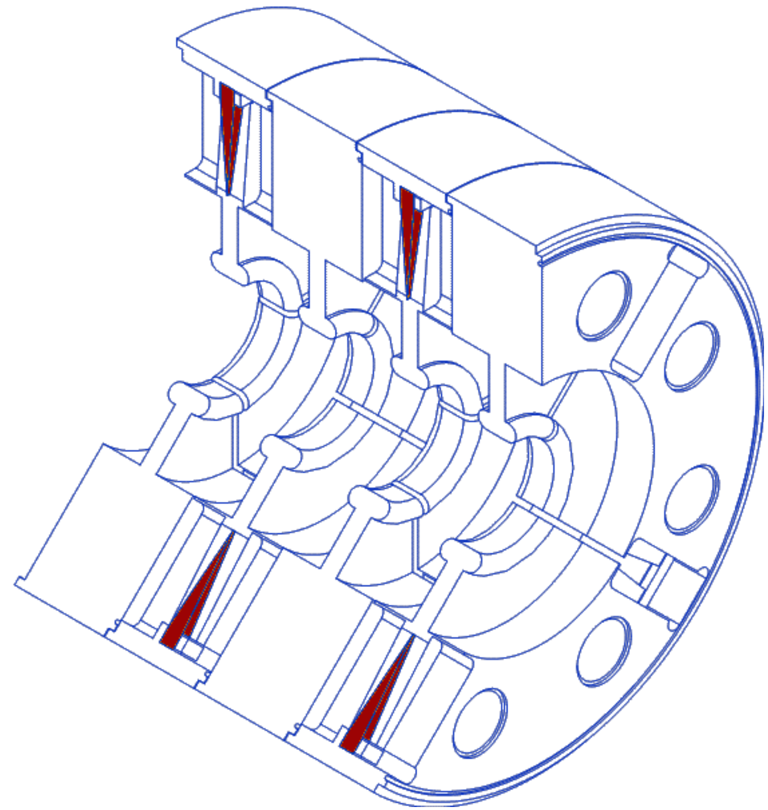
power transferred to beam: 14.66 MW => η~ 97.7%

Principle: SICA

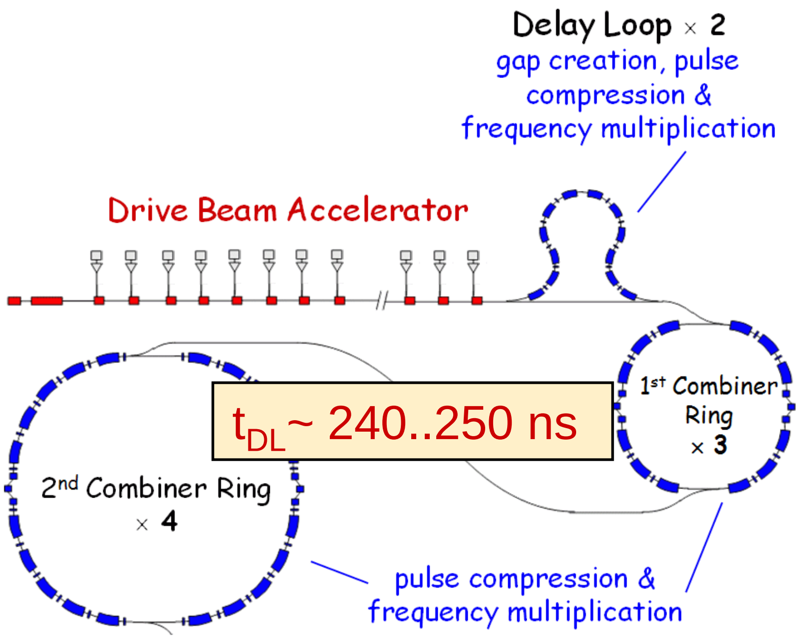
SICA = Slotted Iris – Constant Aperture

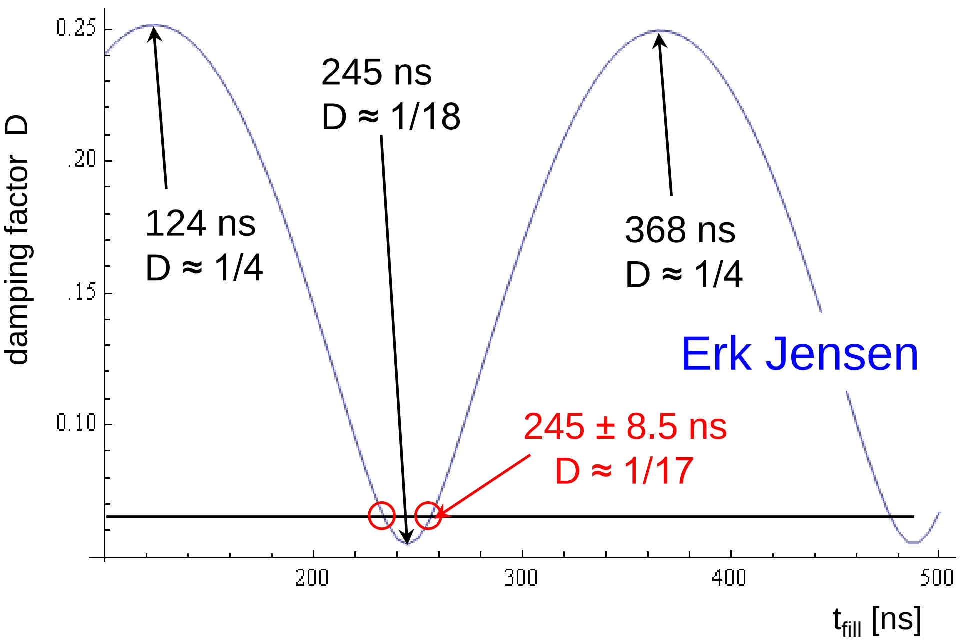
3 GHz SICA structures built and operated in CTF





Principle: filtering





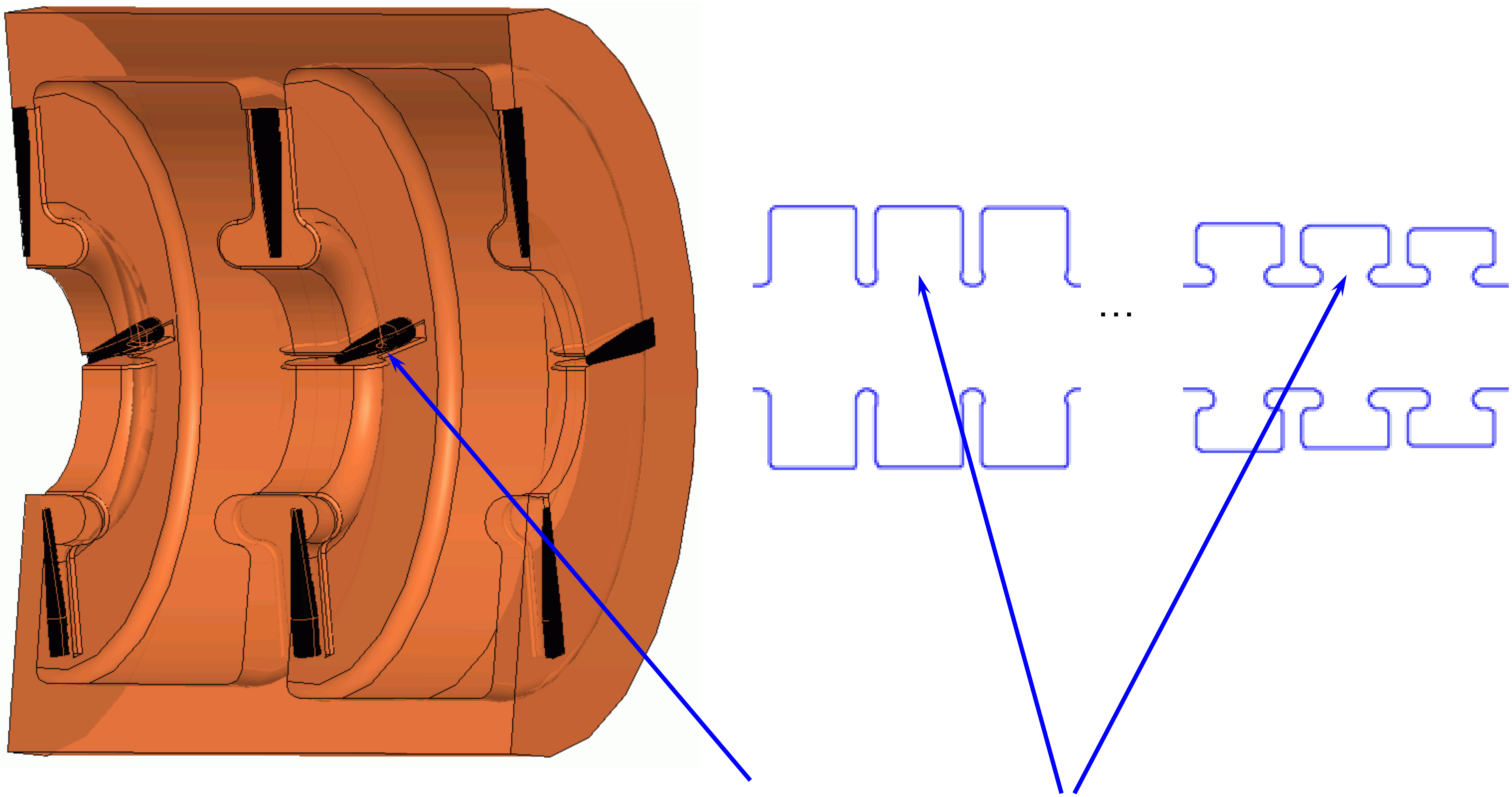
noise at multiples of ~ 4.1 MHz (<=> 240..250 ns) adds up coherently due to combination scheme

=> using fill time of acc. structure to filter 4.1 MHz signals before combination

T_{fill}= 245 ± 8.5 ns

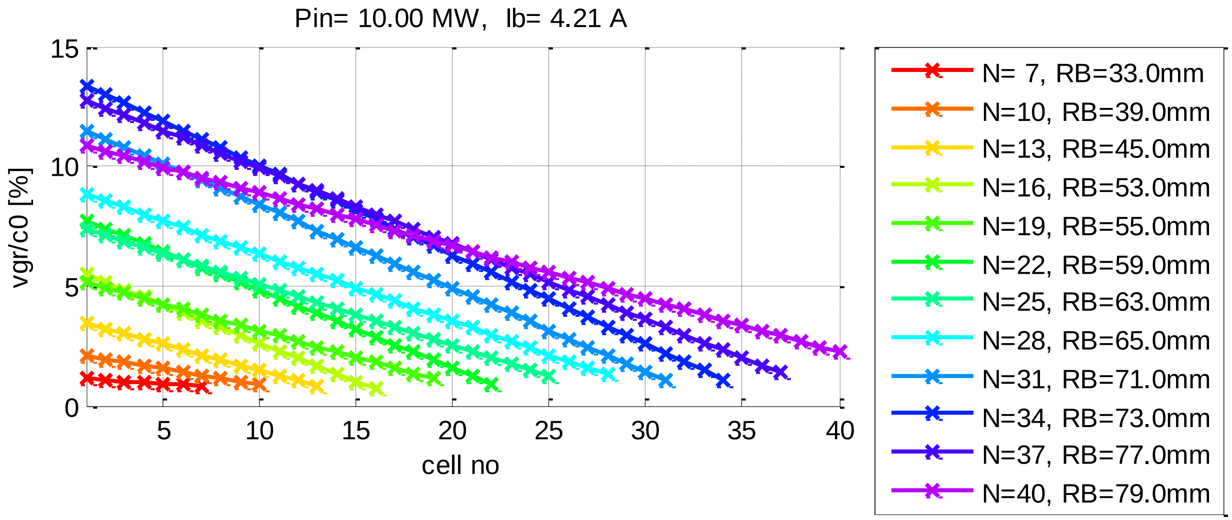
=> damping factor 1/17 ~ 6%

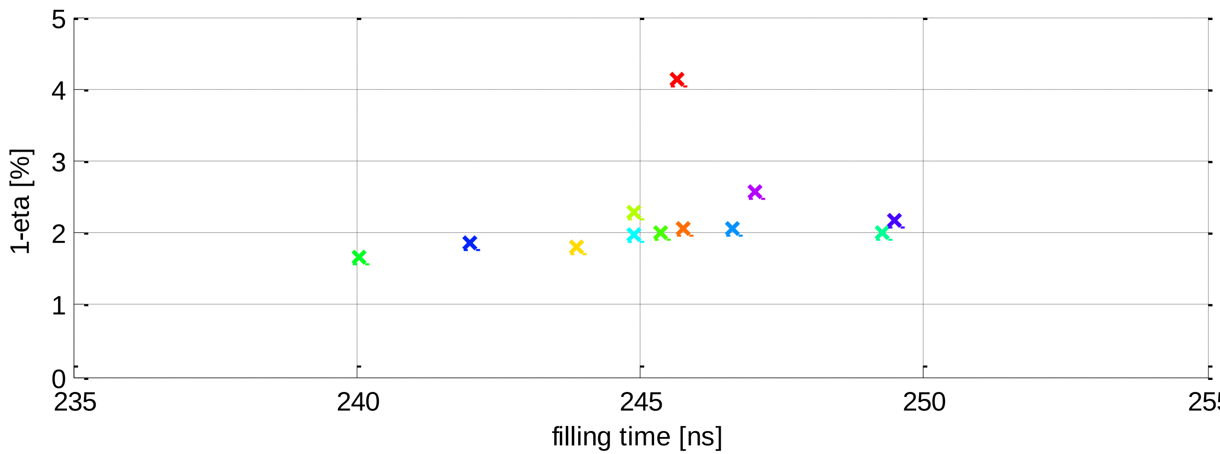
Principle: wakefield reduction



reduction of wakefields by damping and detuning

Structure optimisation





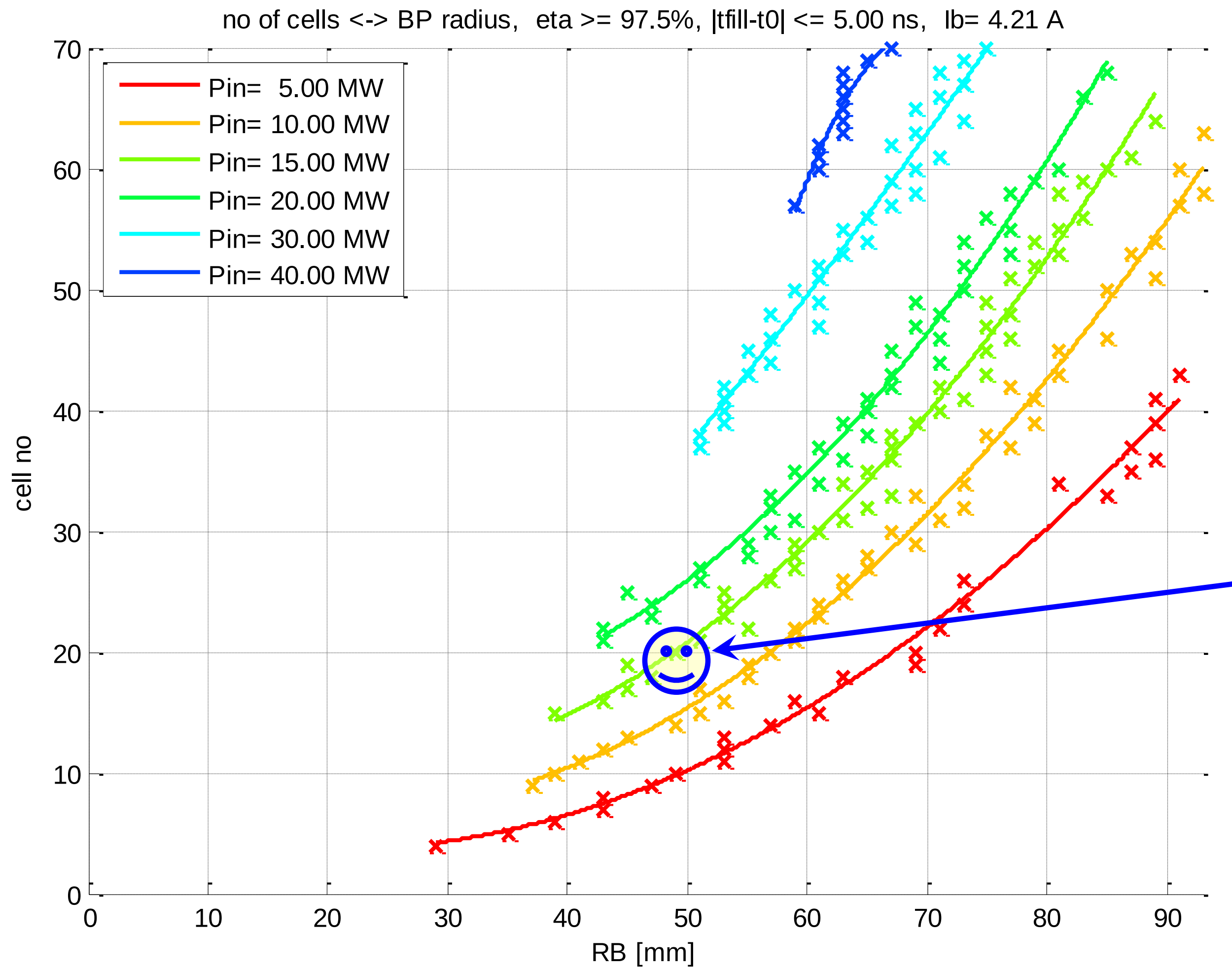
Variables:

1. input power [Pin]
2. structure length = no of cells [N]
3. beam pipe aperture [radius RB]
4. group velocity profile along structure [vgr(n)]

Results:

1. RF to beam efficiency [eta], here “1-eta” used
2. fill time

Structure optimisation



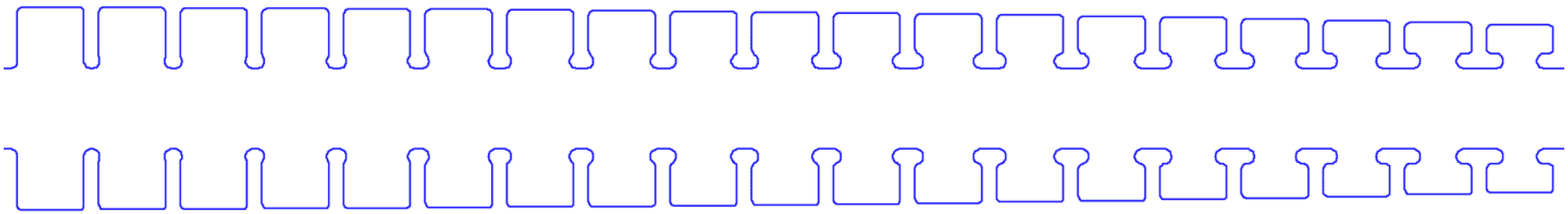
$\eta_{RF} \geq 97.5\ \%$

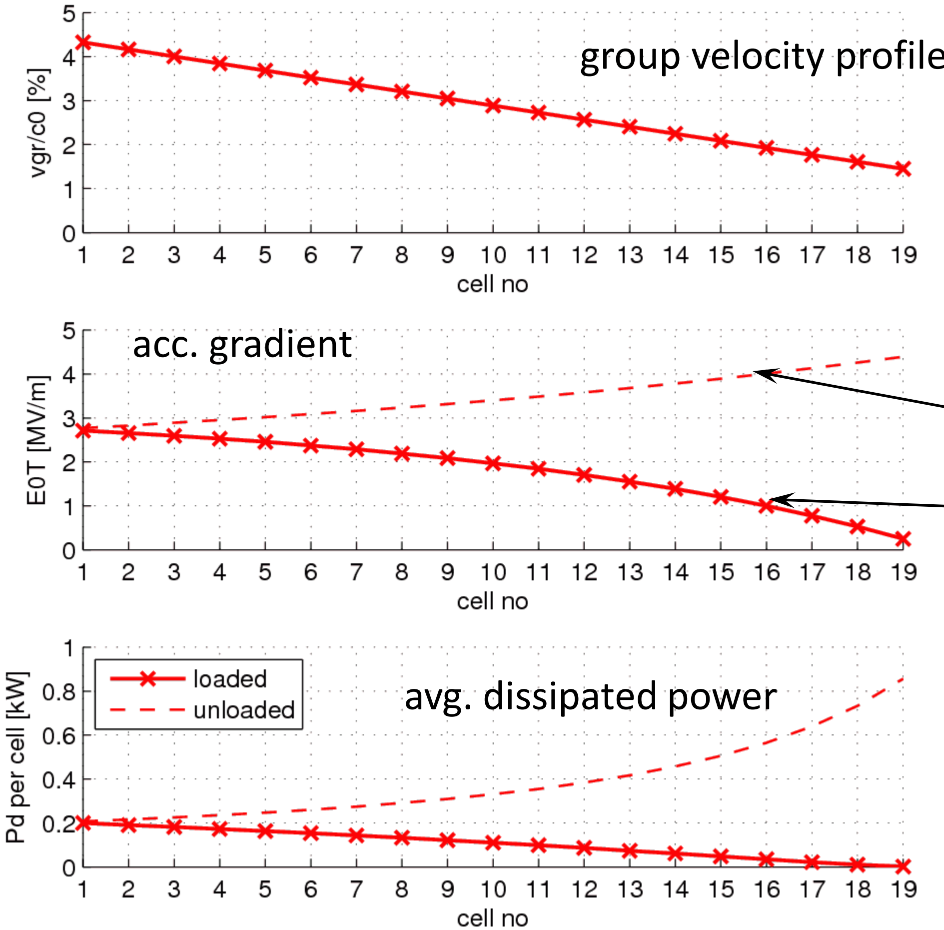
$|t_{fill} - 245\ \text{ns}| \leq 5\ \text{ns}$

P_{in} = 15 MW

Beam dynamic (Avni Aksoy):
RB = 49 mm,
N = 19 cells

Baseline DB accelerating structure





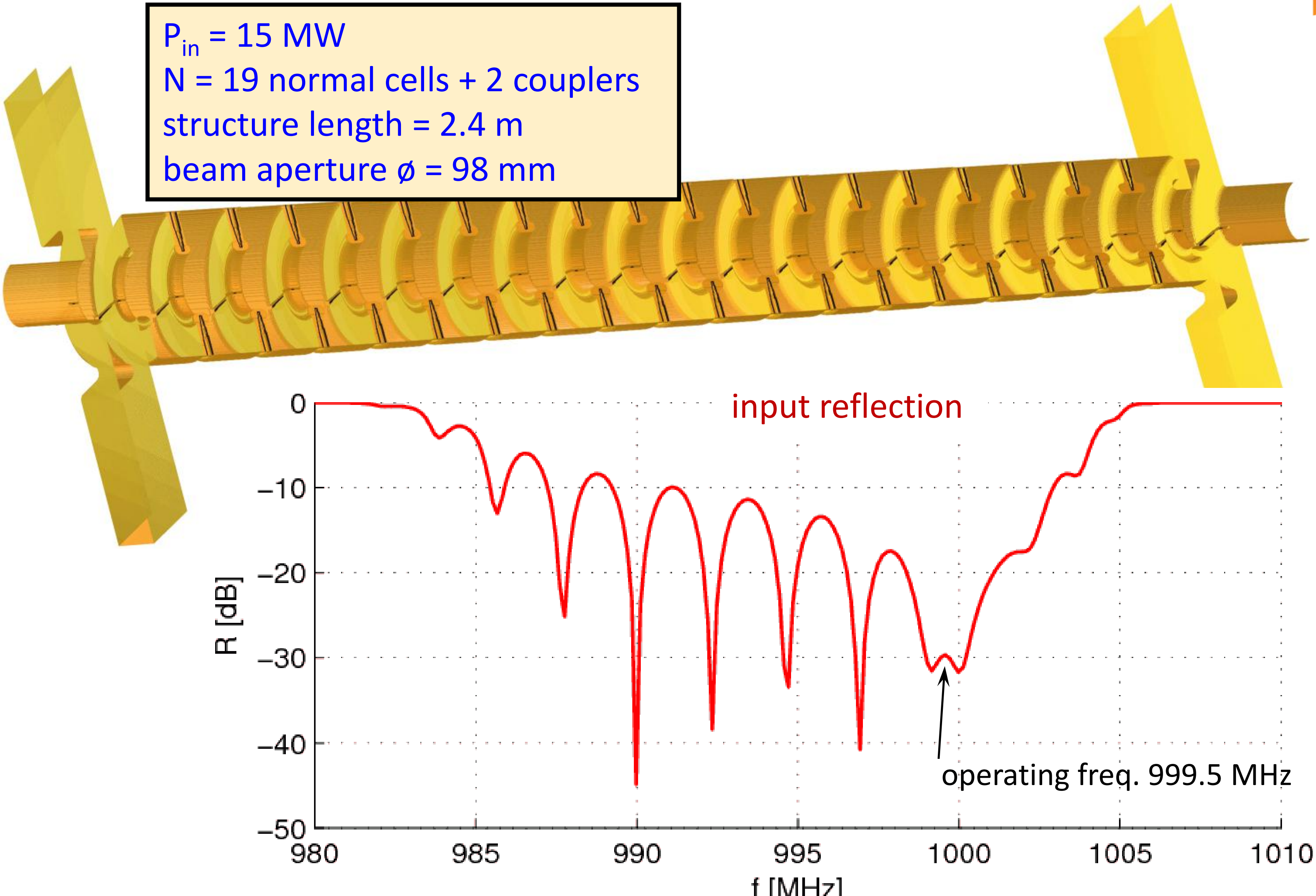
P_{in} = 15 MW
N = 19 normal cells
beam aperture ø = 2*49 = 98 mm

unloaded (no beam)

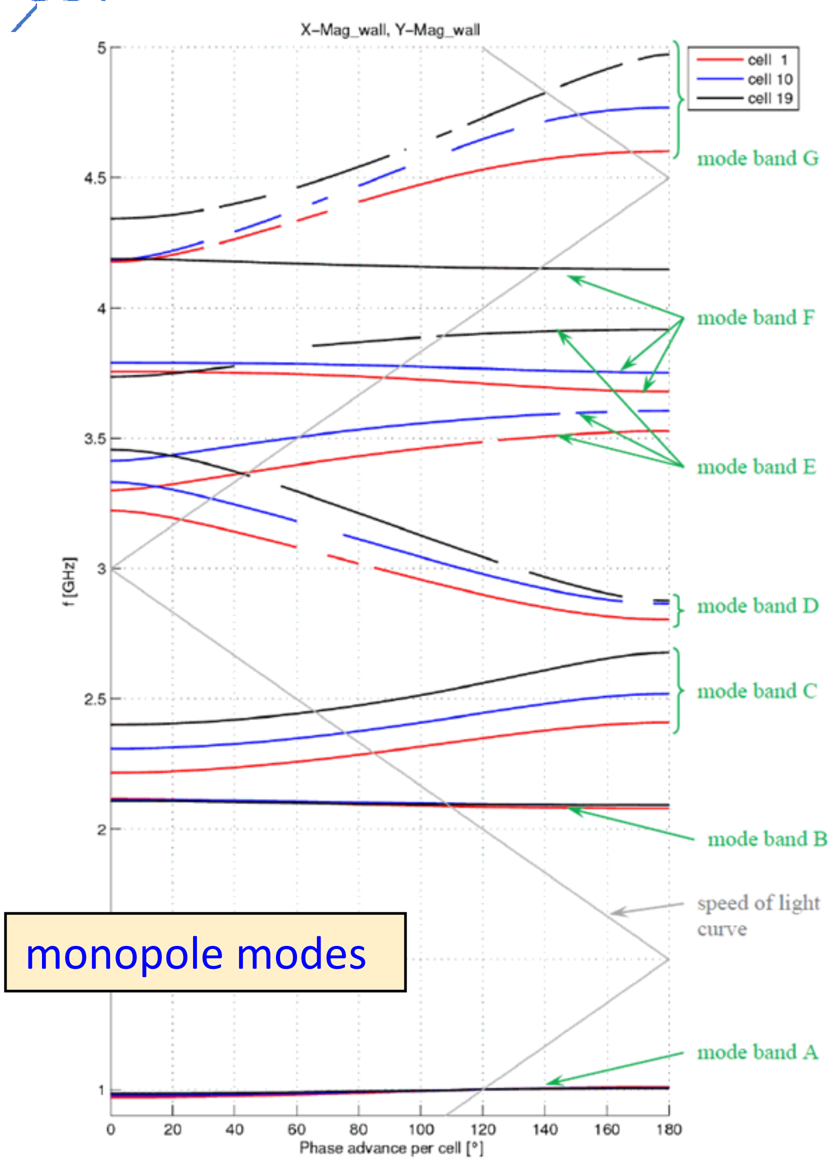
loaded

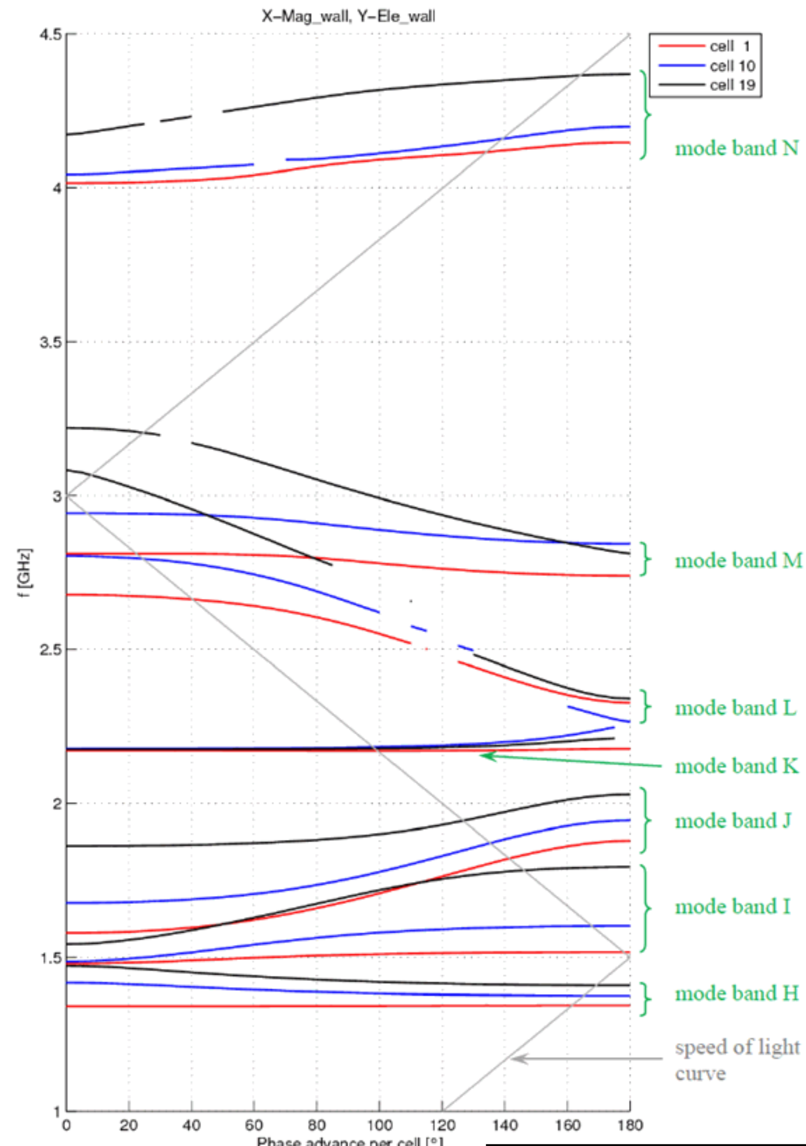
Baseline DB accelerating structure

P_{in} = 15 MW
N = 19 normal cells + 2 couplers
structure length = 2.4 m
beam aperture ø = 98 mm



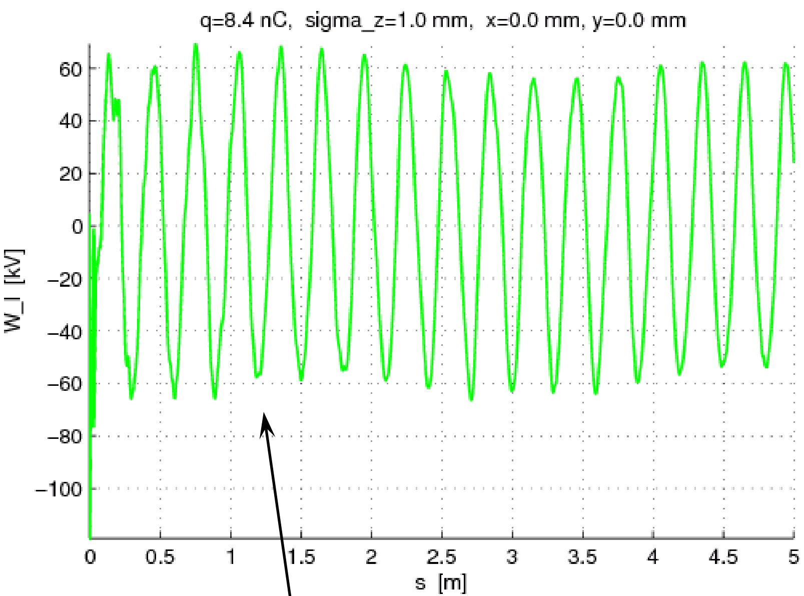
Baseline structure, detuning curves



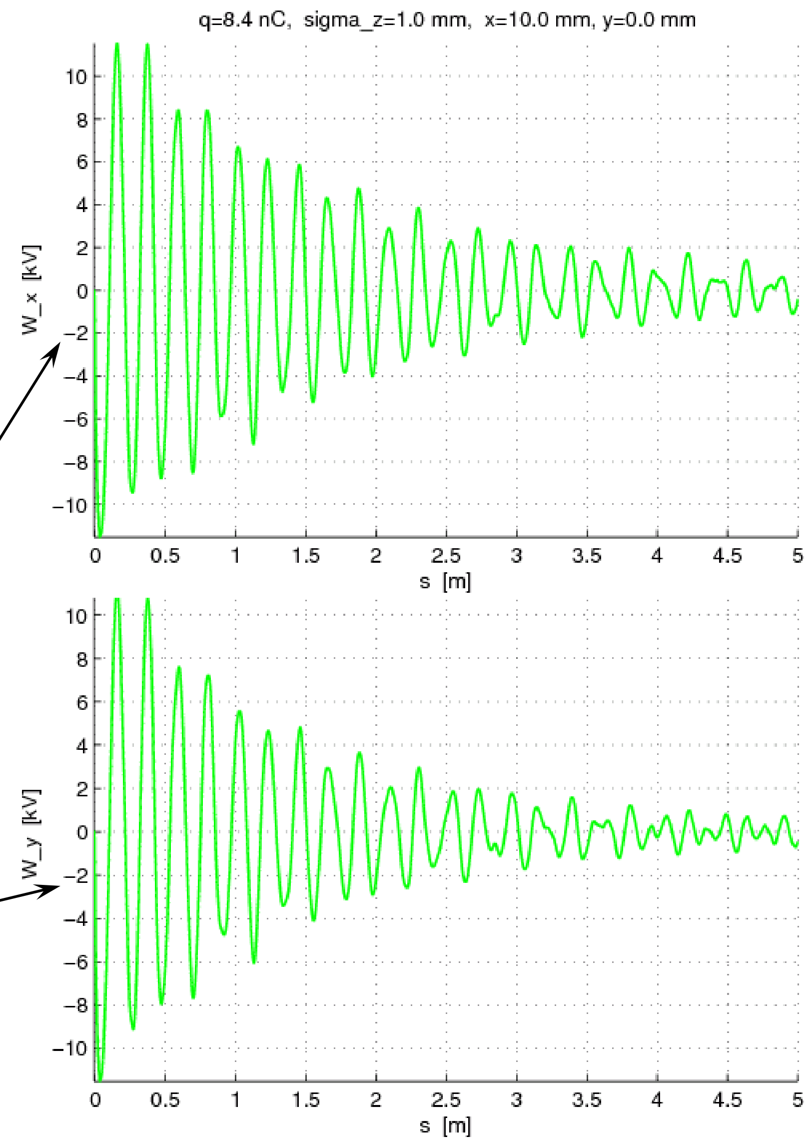


dipole modes

Baseline structure, wakefields



longitudinal wakefield



transverse wakefields

Conclusions

Modulator and klystron:

- challenging specifications
- R & D has been started, further collaborations are welcome

Baseline accelerating structure has been designed

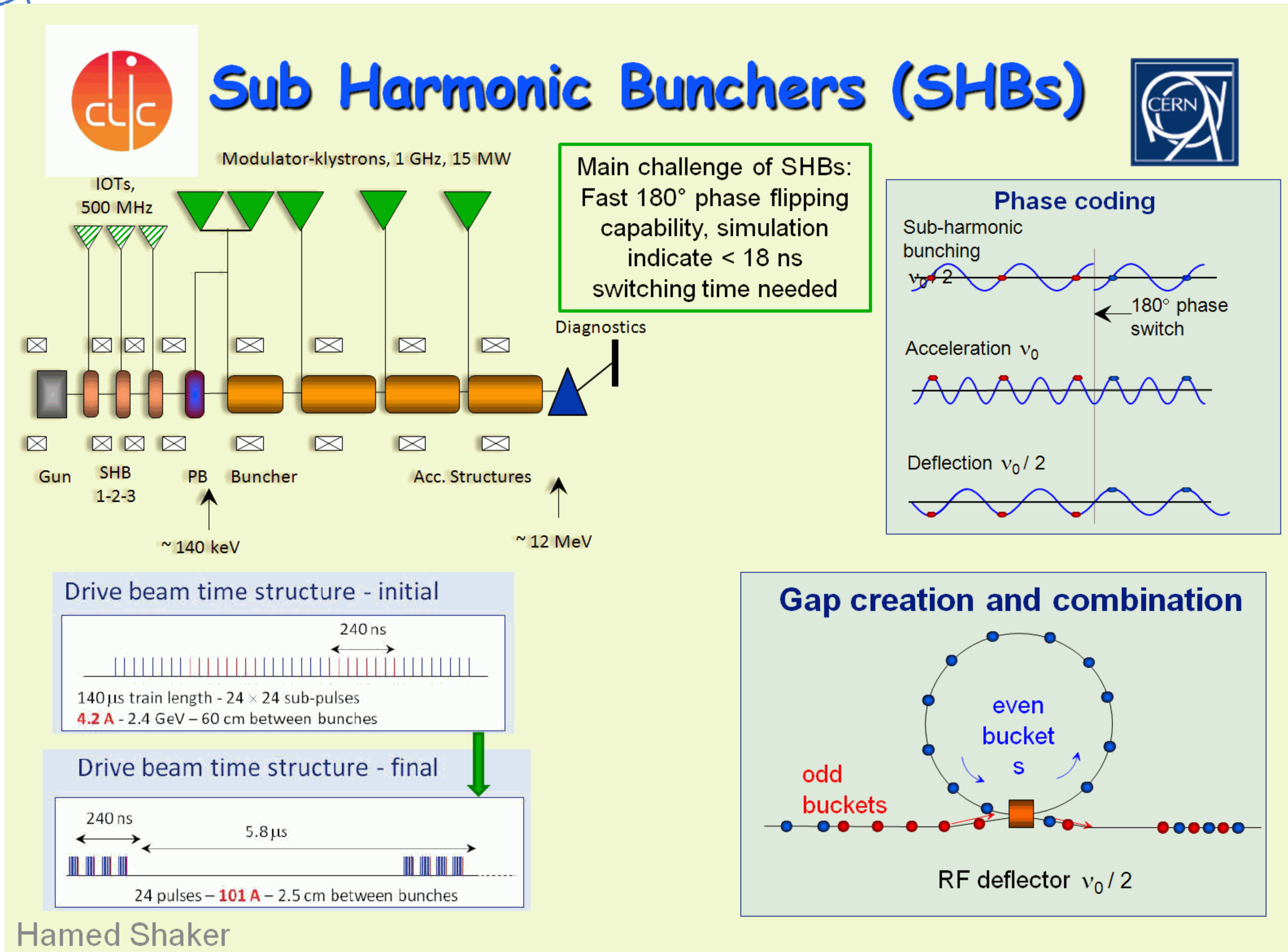
- input power 15 MW, 19+2 cells, beam aperture ø 98 mm
- efficiency ≥ 97.5% (fully beam-loaded), filling time 245 ns ± 5 ns
- wakefields efficiently reduced by damping and detuning

Further research on Drive Beam Modules:

- reduction of total number (combination of klystron power)
- structure re-optimisation, including fabrication cost

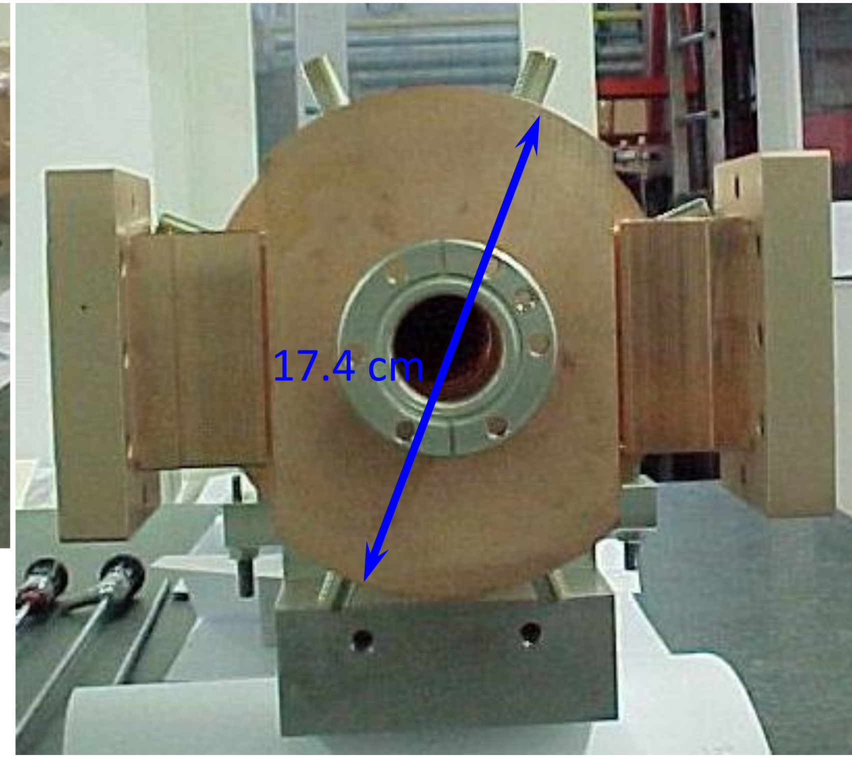
Thank you for your attention

Introduction: CLIC Drive Beam front-end



Steffen Döbert: "Plans for the drive beam front-end and CLIC zero outlook", LCWS 2012

3 GHz DBA structure – Erk Jensen



f_{acc}= 3 GHz

P_{in}= 33 MW

n_{cell}= 33

Length= 1.22 m

$Ø_{outside}$= 17.4 cm

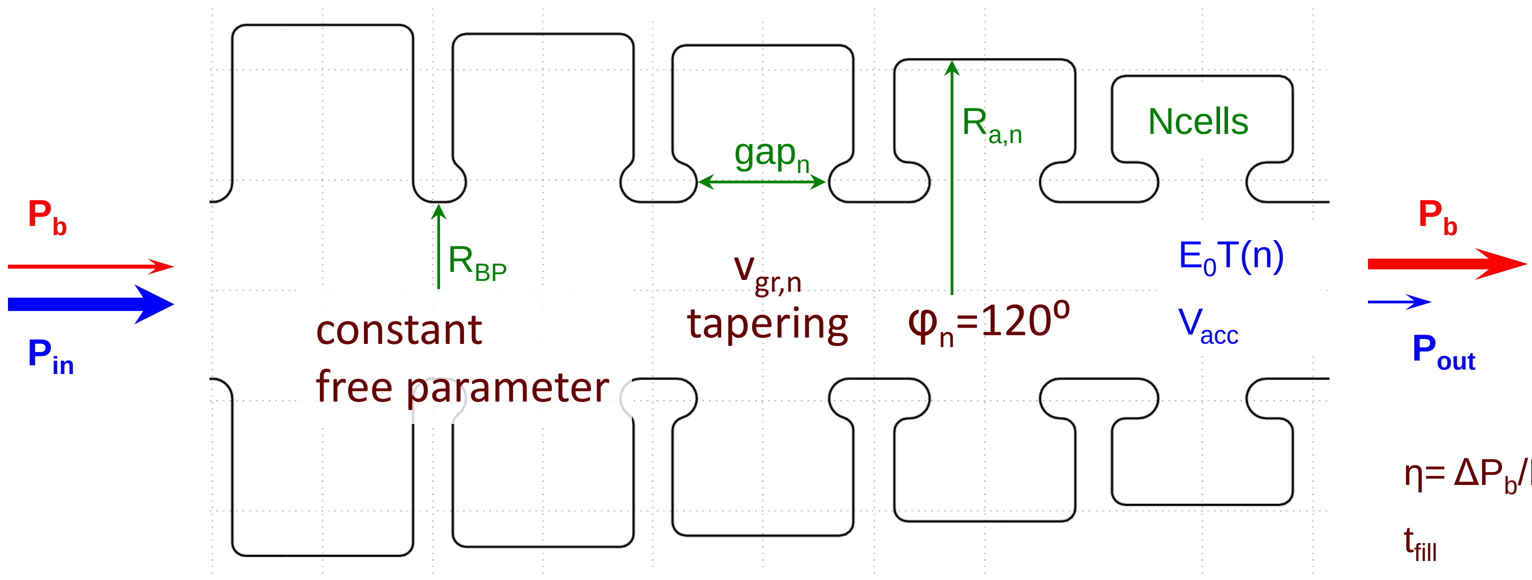
weight ≈ 200 kg

fully beam-loaded,
P_{beam} / P_{RF} = 94%

Corsini, R et al.: First Full Beam Loading Operation with the CTF3 Linac
CERN-AB-2004-057 ; SLAC-PUB-10762 ; CTF-3-NOTE-066 ; CLIC-Note-604

design of TWS

constant aperture

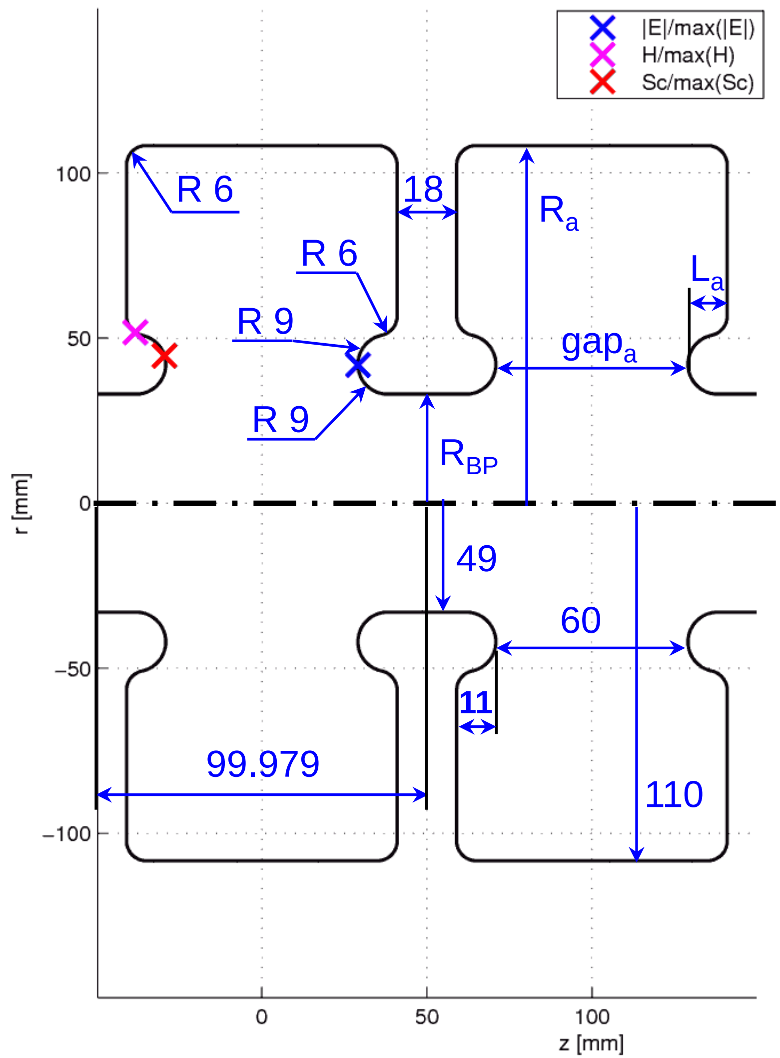


$\eta = \Delta P_b / P_{in}$

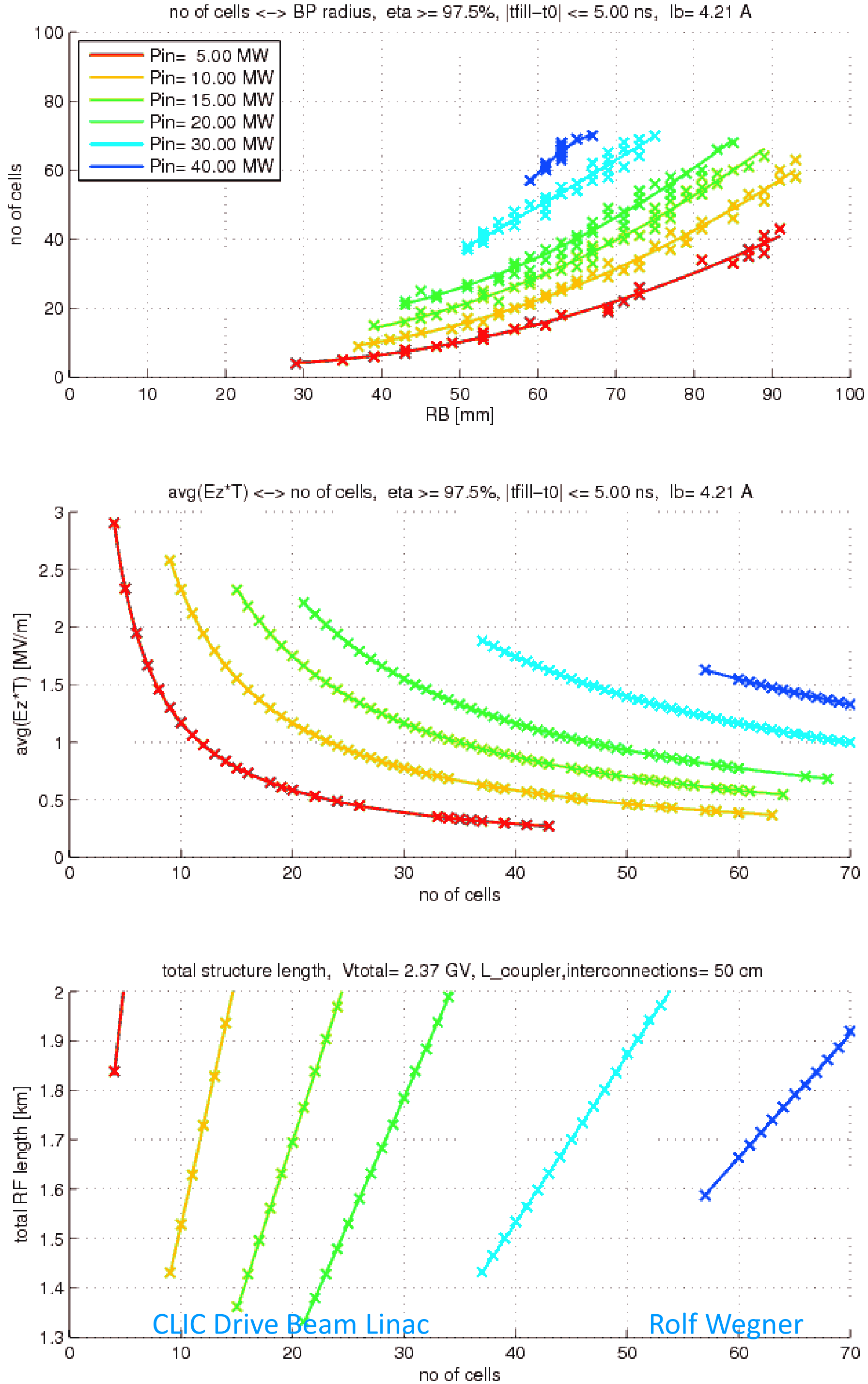
t_{fill}

mode spectrum

basic cell geometry



typical dimensions



no of cells <-> BP radius, eta >= 97.5%, |tfill-t0| <= 5.00 ns, Ib= 4.21 A
Pin= 5.00 MW
Pin= 10.00 MW
Pin= 15.00 MW
Pin= 20.00 MW
Pin= 30.00 MW
Pin= 40.00 MW
no of cells
RB [mm]
avg(Ez*T) <-> no of cells, eta >= 97.5%, |tfill-t0| <= 5.00 ns, Ib= 4.21 A
avg(Ez*T) [MV/m]
no of cells
total structure length, Vtotal= 2.37 GV, L_coupler,interconnections= 50 cm
total RF length [km]
no of cells