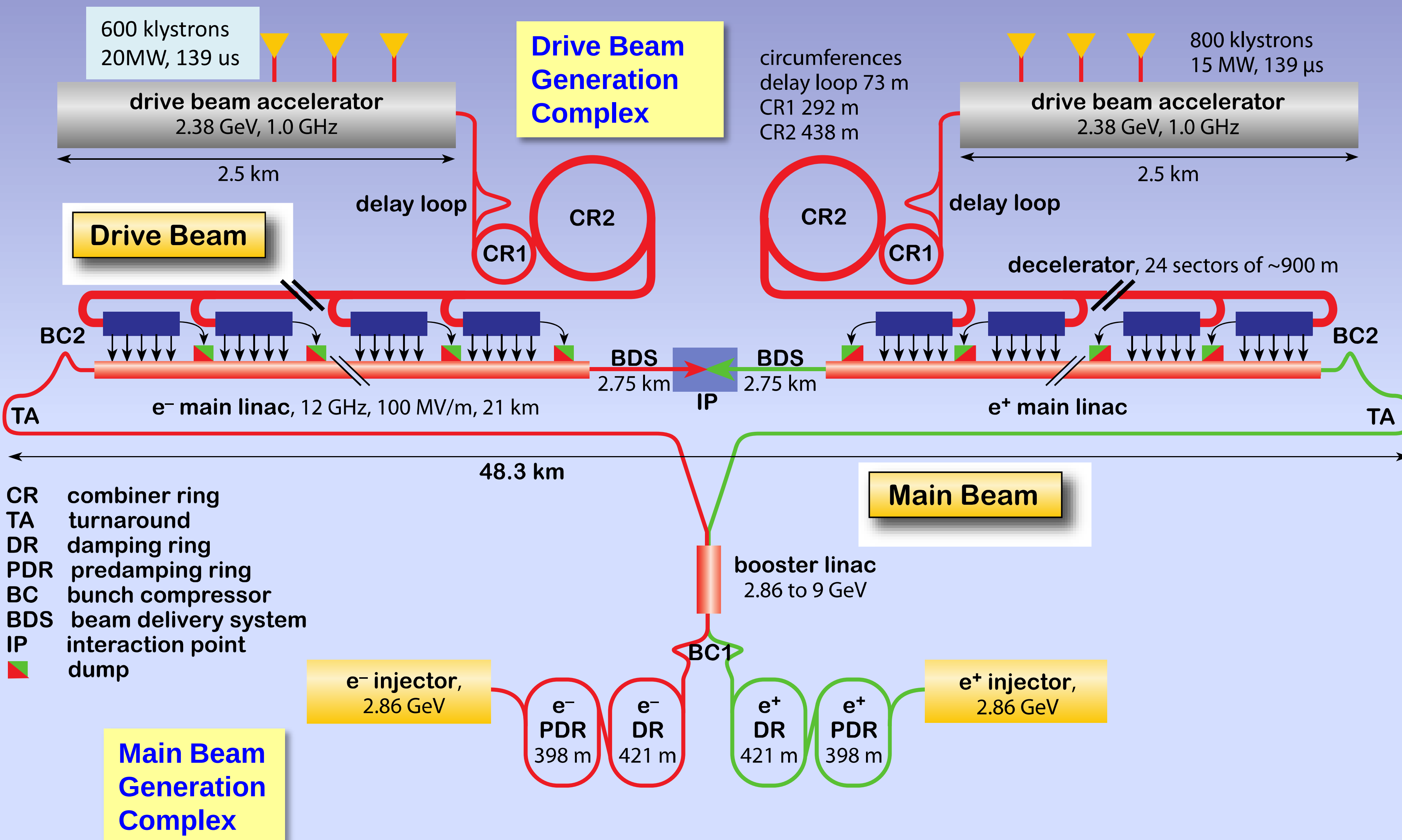
High-efficiency L-band klystron development for the CLIC Drive Beam

- Drive Beam klystron requirements
- Optimization of parameters
- Development status

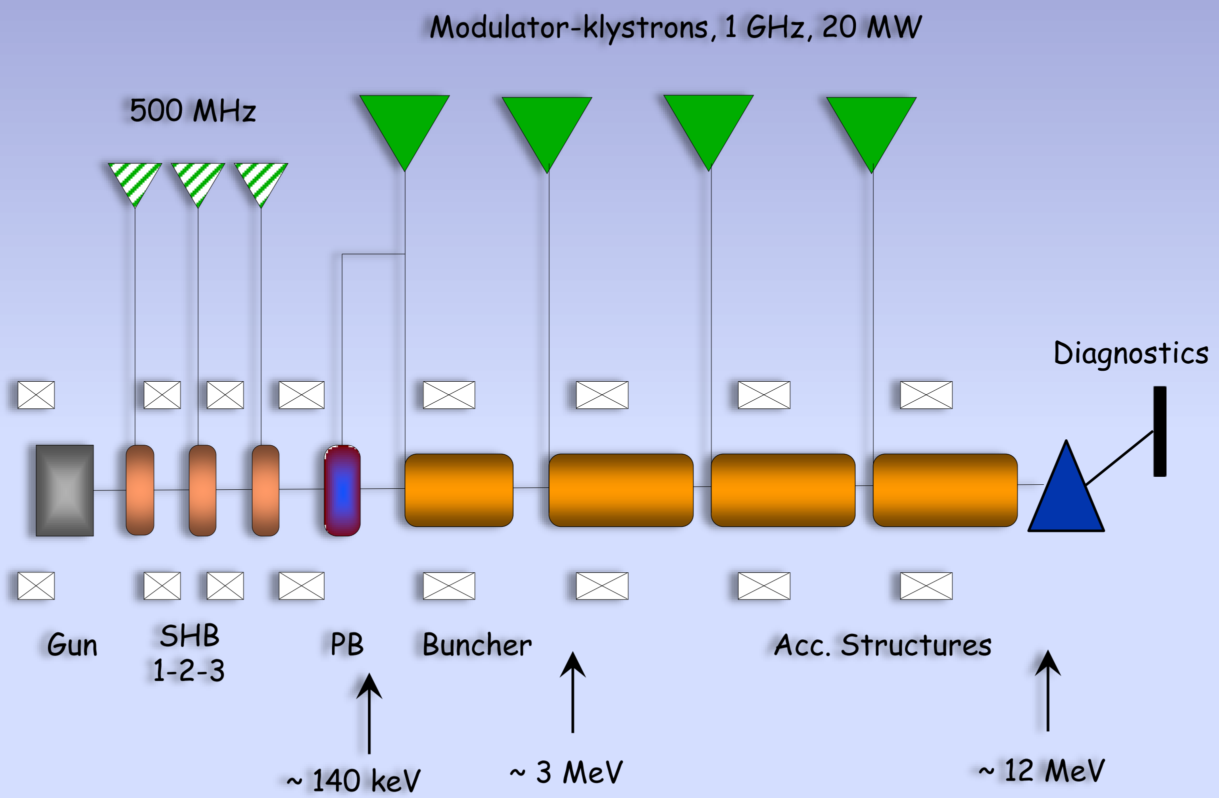
Steffen Döbert, BE-RF

CLIC Layout at 3 TeV



- CR combiner ring
- TA turnaround
- DR damping ring
- PDR predamping ring
- BC bunch compressor
- BDS beam delivery system
- IP interaction point
- dump

CLIC DB front end, Post CDR Project



For time being only major component development:
GUN, SHB, high bandwidth 500 MHz source, 1 GHZ MBK, modulator and fully loaded accelerating structure

CLIC Drive Beam requirements

<u>3 TeV CLIC (CDR):</u>

1230 klystrons, 20 MW, 150 μs, 50 Hz

24.57 GW peak power, 184 MW average

0.05 ° intra bunch jitter, 0.2% amplitude

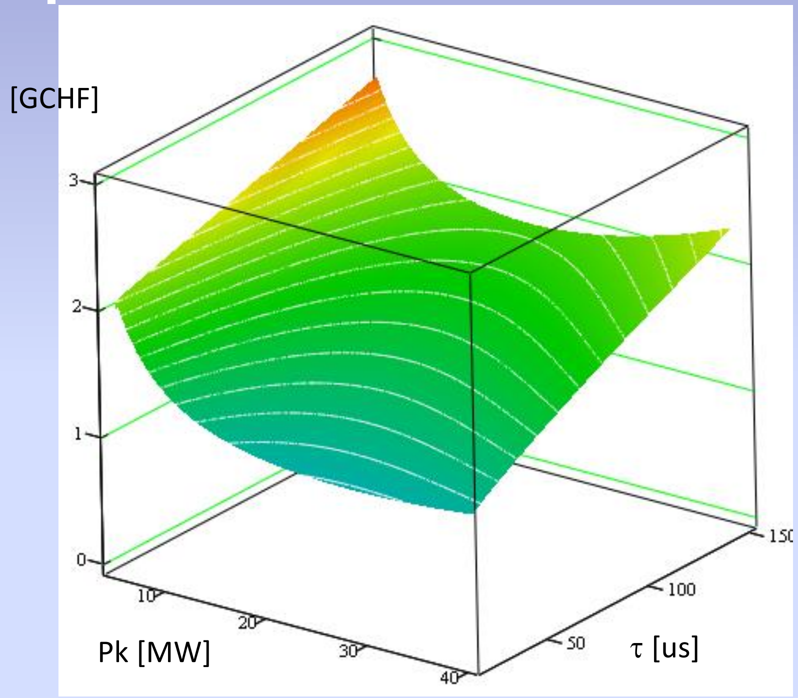
500 GeV about half the klystrons and factor 6 in beam power depending on scenario

Main energy 'consumer' in CLIC (~50 % for 3 TeV)

CLIC Drive Beam optimization

- Rebaselineing effort after the CDR with emphasis on low energy machine, cost and power consumption
- Obviously drive beam and its power source in the focus
- On the other hand need to fix some parameters to start developing hardware which takes a long time
- Frequency dependence on cost and power consumption briefly studied
- Linac cost studied as a function of klystron peak power

Total Linac cost



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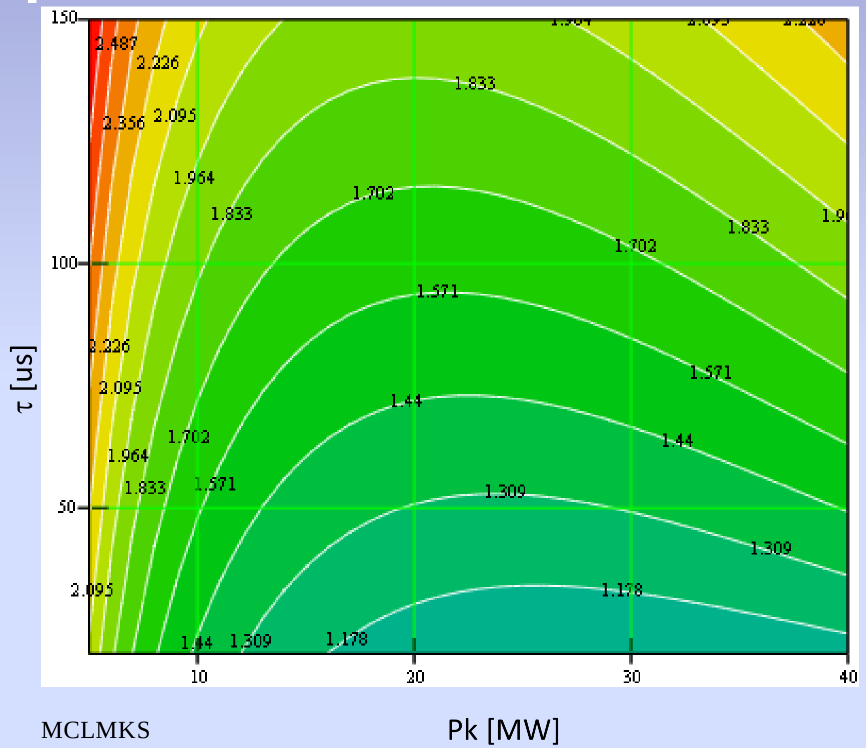
Total cost [GCHF]



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Roberto Corsini

Klystron parameters

PARAMETER	VALUE	UNITS
RF Frequency	999.516	MHz
Bandwidth at -1dB	≥ 1	MHz
RF Power:		
Peak Power	≥ 20	MW
Average Power	150	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, ≤ 180	kV
Tolerable peak reverse voltage	tbd	kV
Efficiency at peak power	67 ≤ 70	%
RF gain at peak power	tbd, > 48	dB
Perveance	tbd	$\mu A/V^{1.5}$
Stability of RF output signal at nominal working point		
RF phase ripple [*]	±1 (max)	RF deg
RF amplitude ripple	±1 (max)	%
Pulse failures (arcs etc.) during 14 hour continuous test period	≤ 1-2	
Matching load, fundamental and 2nd harmonic	tbd	VSWR
Average radiation at 0.1m distance from klystron	≤ 1	µSv/h
Output waveguide type,	WR975 pressurised	2-3 bar

Status of the CLIC L-band klystron

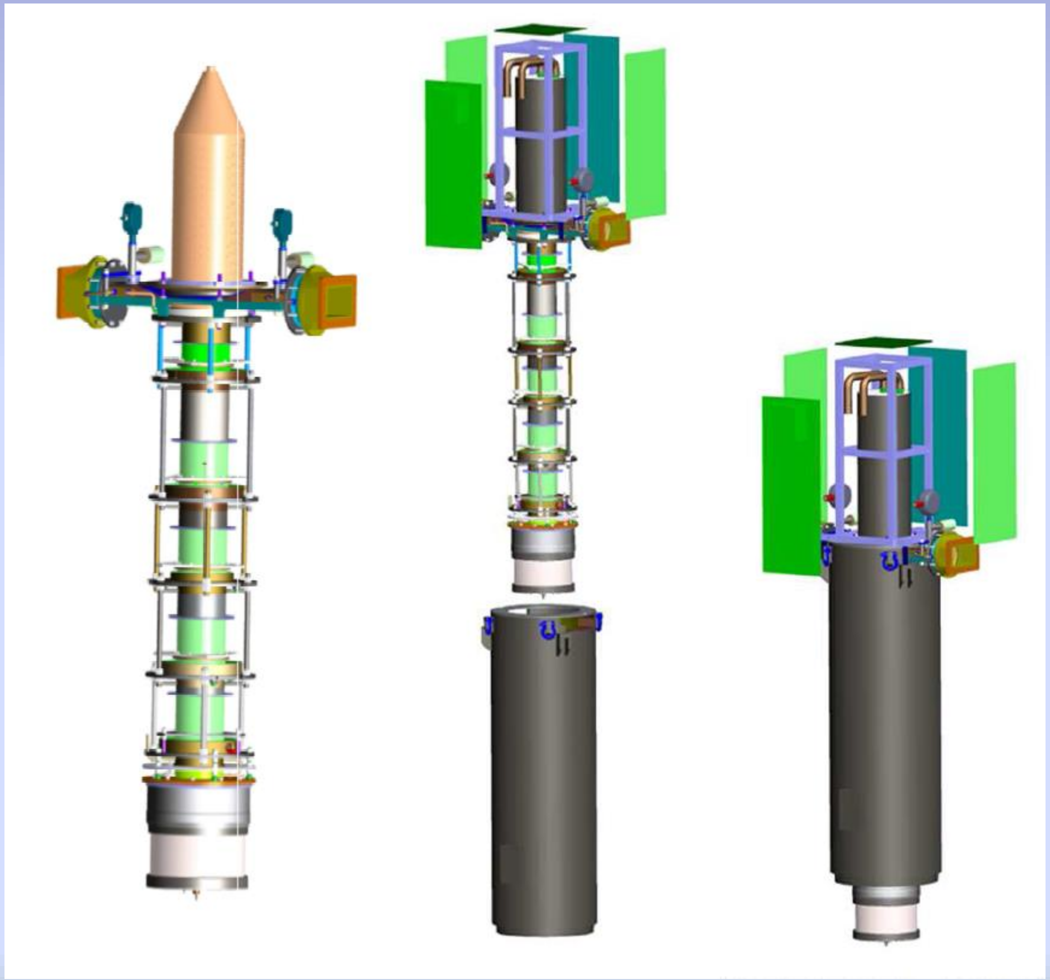
- Strategy: Try to develop prototypes with two different vendors to minimize technical and financial risk

- Launched two contracts for the klystron development in 2014
  One with Thales and one with Toshiba
  Design approved in 2015 for both klystrons

- In parallel modulator development program in the power group
  First modulator being build by ETHZ and second designed by Laval University (Canada)
  See presentation by Davide Aguglia later today

Thales Electron Devices TH1803

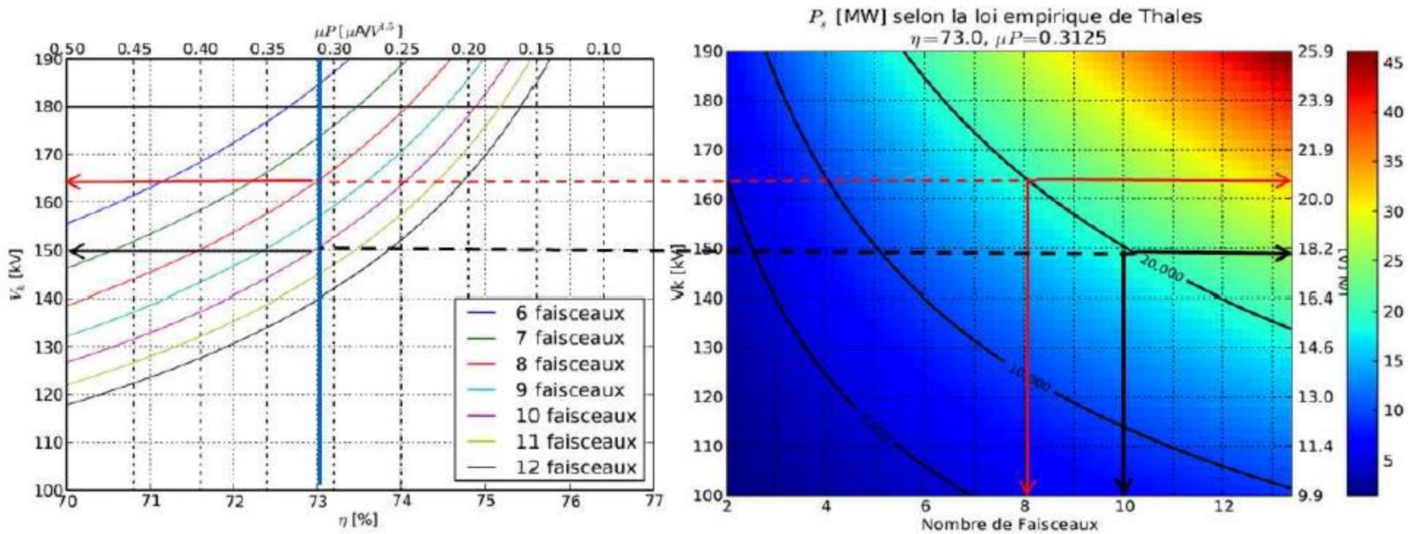
10 beam multi beam klystrons, 153 kV, 77 % efficiency calculated
Design approved, delivery spring 2016



Designer: Rodolphe Marchesin

Klystron design

- Efficiency and number of beam

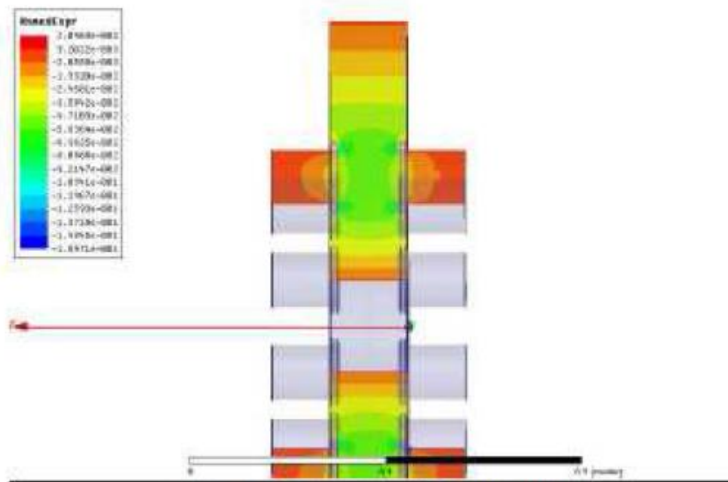


- Design parameter
  - Vk = 150 kV ; Ik = 182 A
  - 10 beams, I/beam = 18.2 A
  - Low cathode current density < 3A/cm²

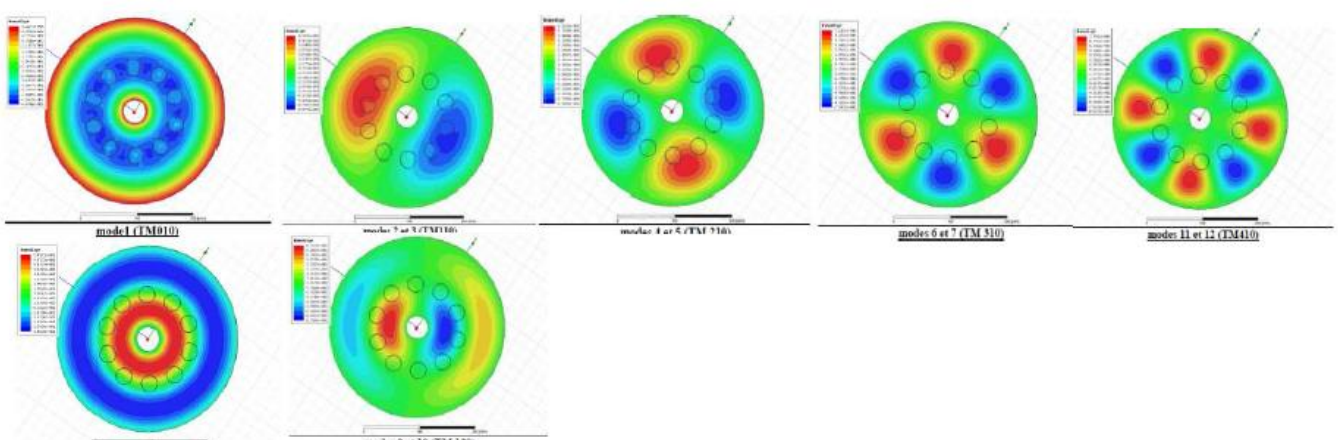
μP/beam (μA.V$^{-3/2}$)	**0.31**		
HV pulse length (μs)	**160**		
Po (MW)	**20**		
Nb beams	**10**		
Po/beam (MW)	**2**		
	η (%)	**Vk (kV)**	**Ik (A)**
efficiency min	**67**	155.5	192
efficiency typ	**70**	152.7	187
efficiency max	**73**	150	182

Klystron intermediate cavity

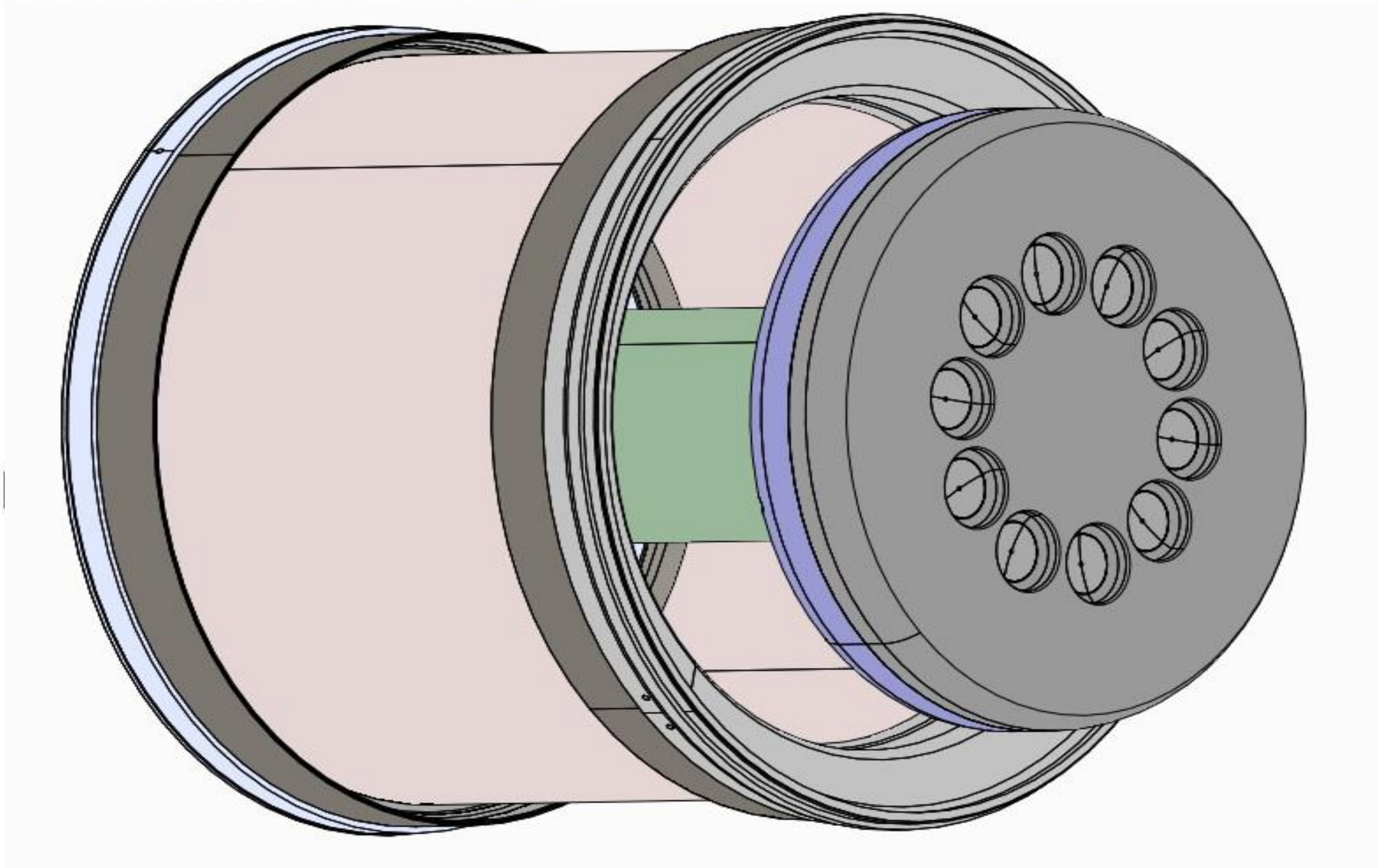
- Coaxial cavity type allows
  - High number of beams
  - High separation distance between beams
  - Management of cathode diameter size
  - Integration of an harmonic cavity
  - High R/Q > 150 Ohm



Ez mode 1 coupe longitudinale

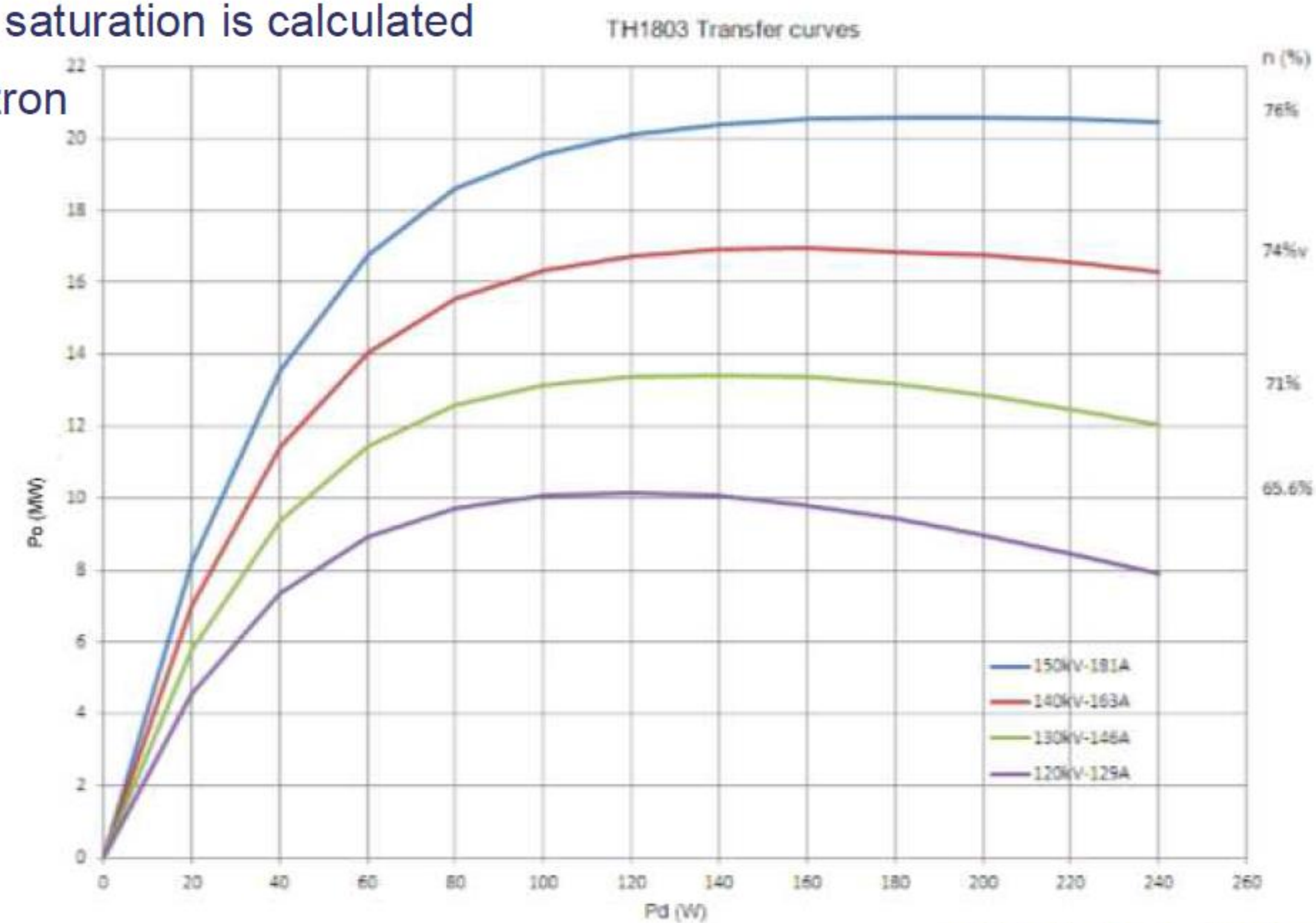


10 cathodes gun design



Transfer curve

- Output power > 20 MW is obtained at saturation for beam power 150kV x 181 A
- Saturated drive power = 180 W
- 76% efficiency at saturation is calculated
- No reflected electron



THALES

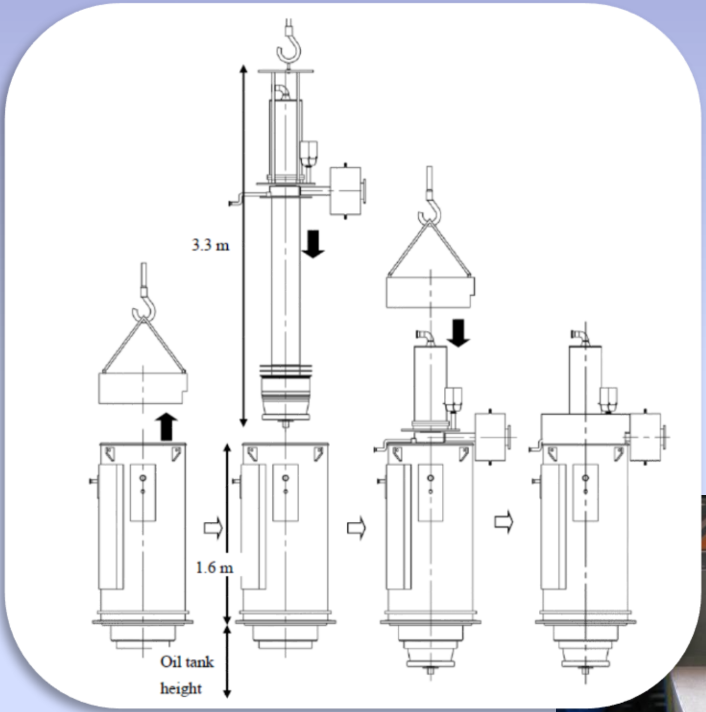
Thales Electron Devices TH1803

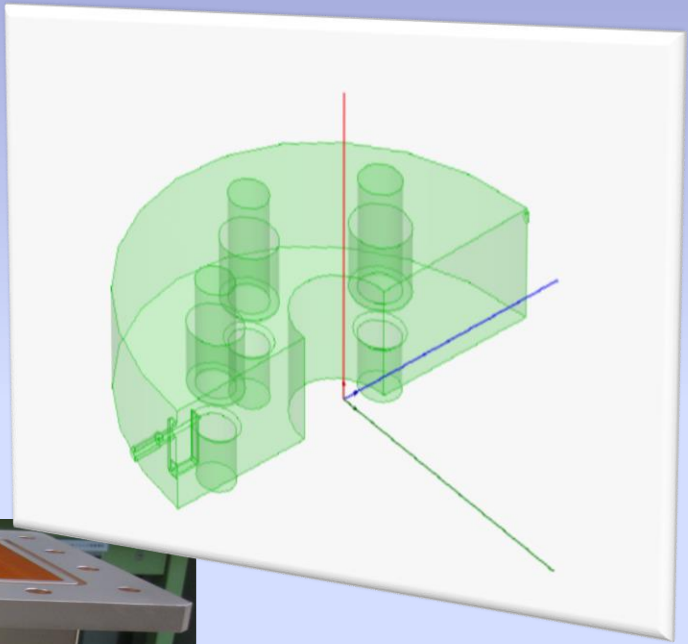
Klystron components under fabrication:

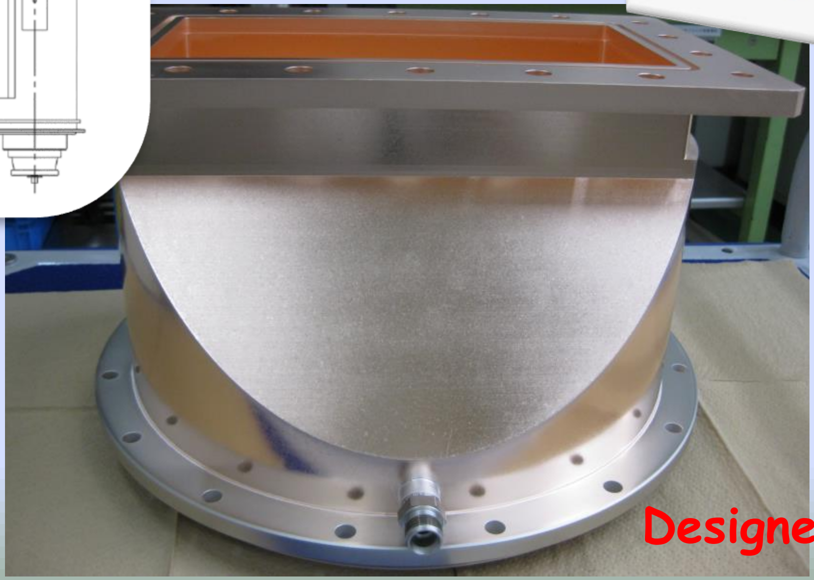
- Collector
- RF cavities
- Focusing magnet
- Cathodes

Toshiba Electron Tubes E37503

6 beam multi beam klystrons, 75 % efficiency calculated
Design approved, Delivery summer 2016







Designer: Yoshihisa Okubo

Toshiba Electron Tubes E37503

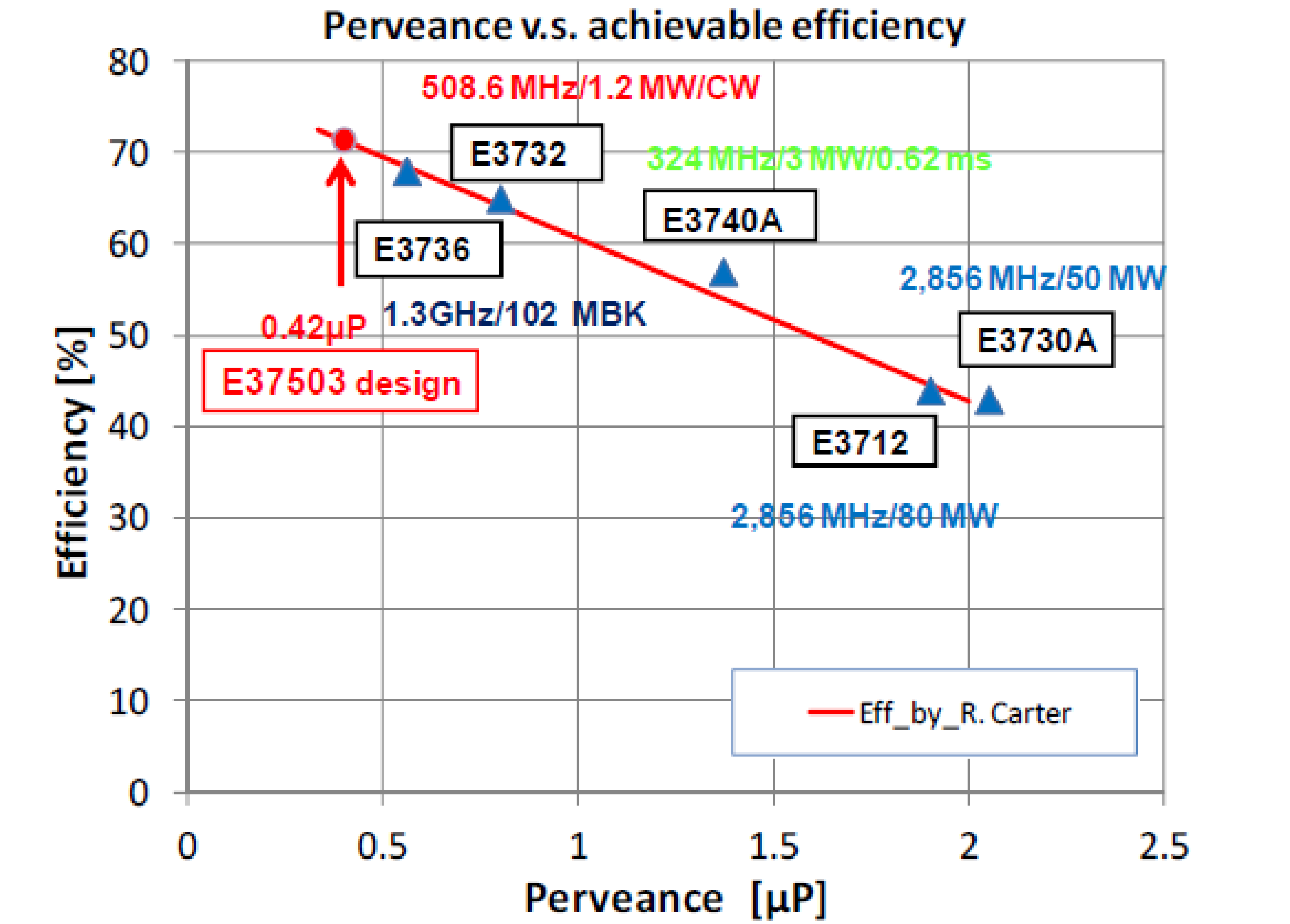


Figure1: Expected efficiency by an empirical relation between perveance and achievable efficiency

Toshiba Electron Tubes E37503

	Unit	6 beams design	8 beams design	
		Standard design	Shorter length design	Standard design
Beam voltage	kV	169	168.2	
Cathode current per beam	A	29.2	21.4	
Expected efficiency	%	71	73	
Perveance per beam	$\mu A/V^{3/2}$	0.42	0.31	
Reduced plasma wave length	m	4.05	4.69	
Brillouin magnetic field strength	Gauss	331	284	
Cathode loading	A/cm^2	1.75	2.2~2.8	
Estimated tube length	m	3	3	3.24
Expected power gain Reference to six beams design	ΔdB	0	-3.6	0

Toshiba Electron Tubes E37503

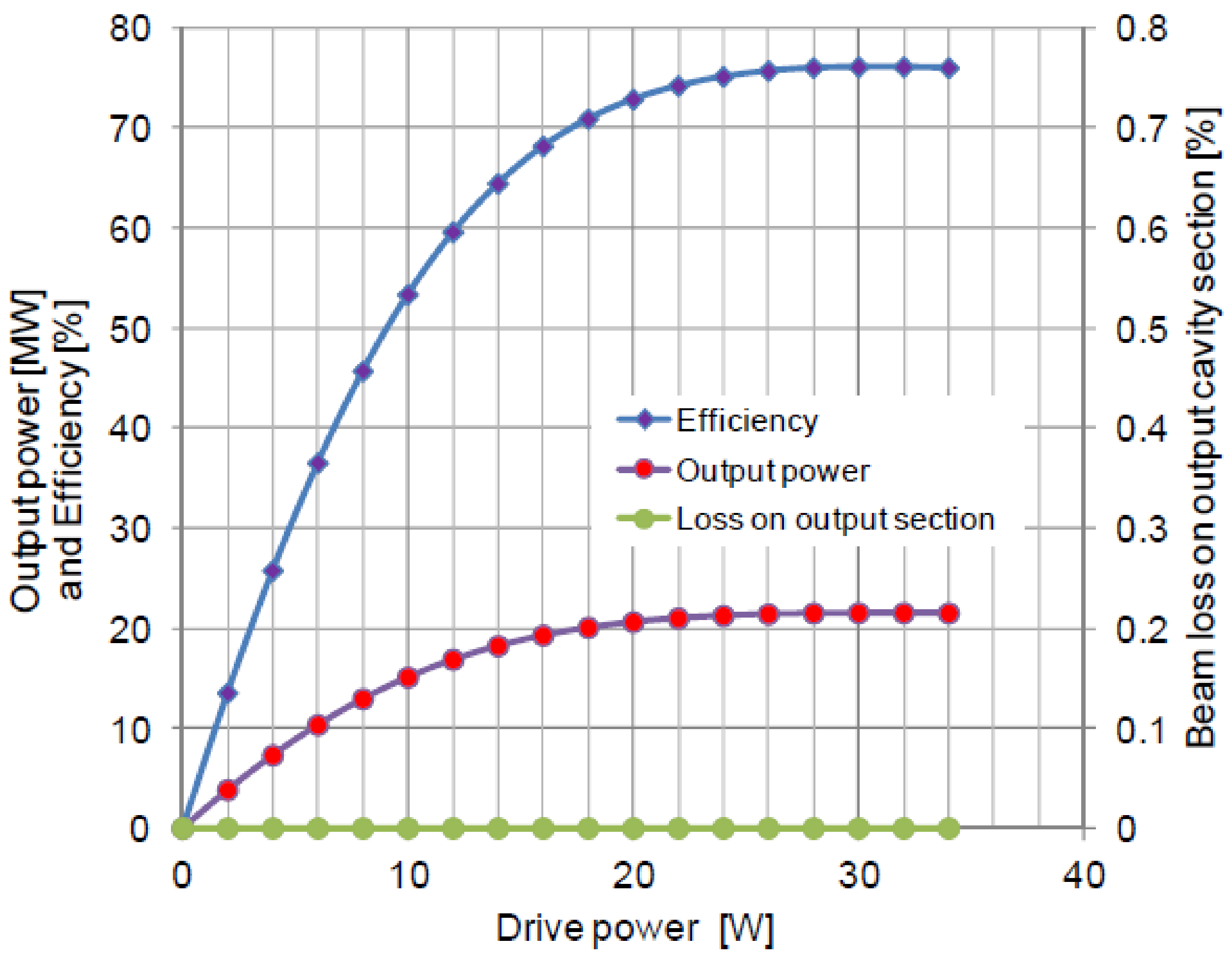


Figure 13: Transfer characteristics (simulation results by EMSYS)

(Beam voltage: 166 kV, Beam current: 170.5 A(total))

Toshiba Electron Tubes E37503

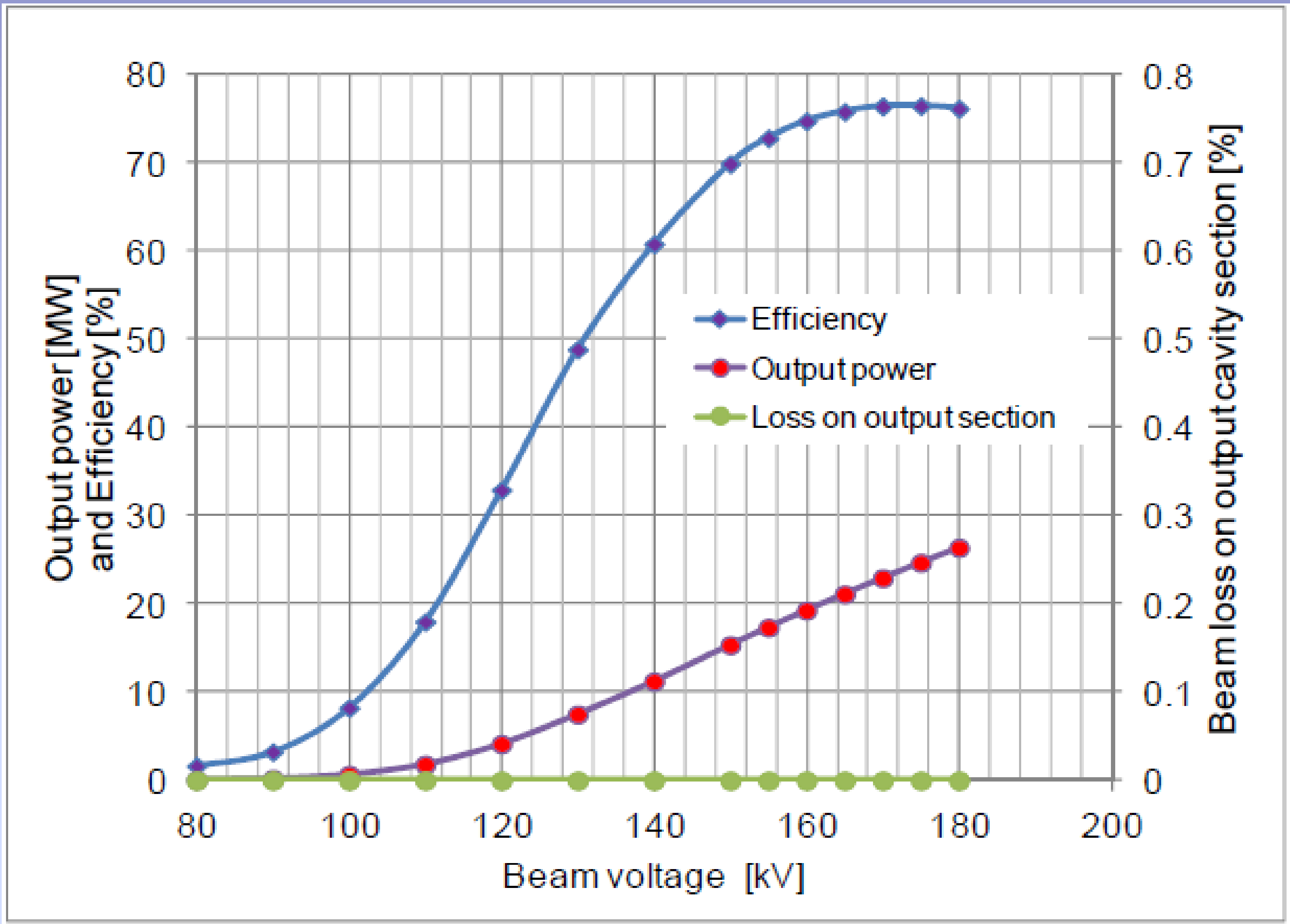
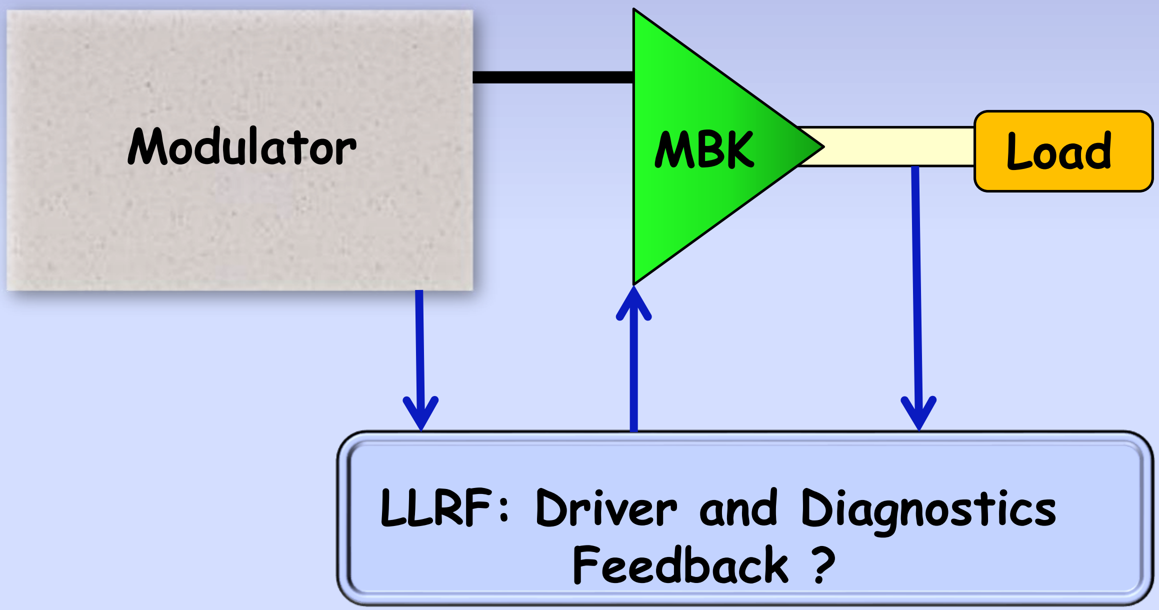


Figure 12: Saturated output characteristics (simulation results by EMSYS)

(Drive power : 192 W(total))

Klystron Test Stand

Together with the Modulator team a test stand is under construction to test the rf unit in detail with special emphasis on the stability measurements



Conclusion and outlook

- Thales and Toshiba developing each a 1 GHz MBK to our specifications
- Both design reports have been finished and accepted Efficiencies in excess of 70% are predicted
- Manufacturing ongoing with planned delivery this summer
- We are looking forward to see these milestones for CLIC and other applications realized
- Very pleasant collaboration with industry so far

End