CLIC Project Meeting #41

Dec 13, 2021, 1:30 PM → Dec 14, 2021, 1:00 PM Europe/Zurich

CERN

Klystron developments for CLIC. X-band and L-band prospects

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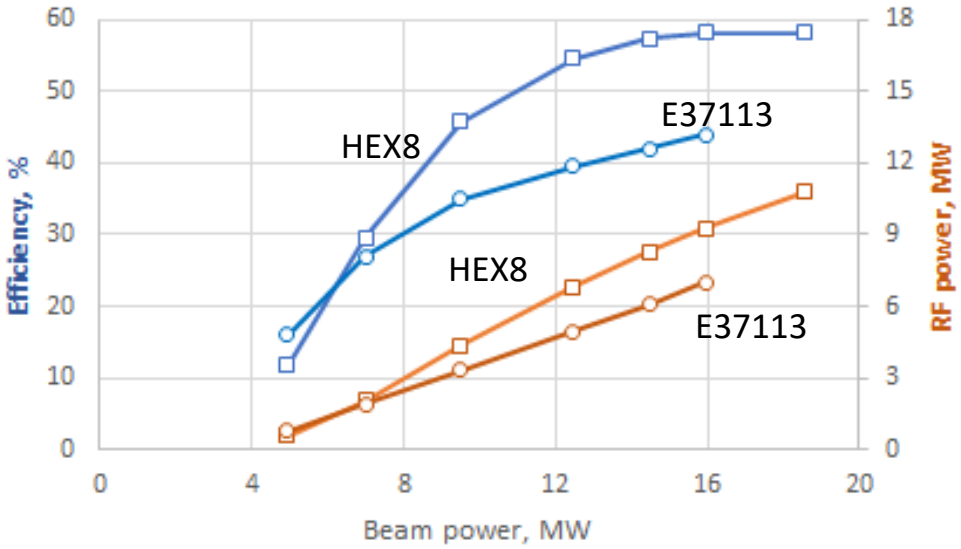
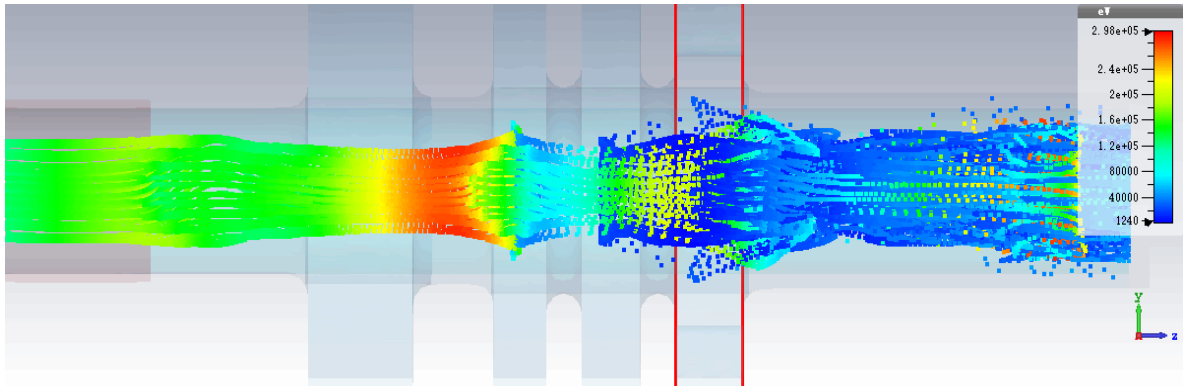
X-band HE klystrons
8MW - 60MW

Retro-fit High Efficiency 8 MW, 12 GHz klystron (CERN/Canon).





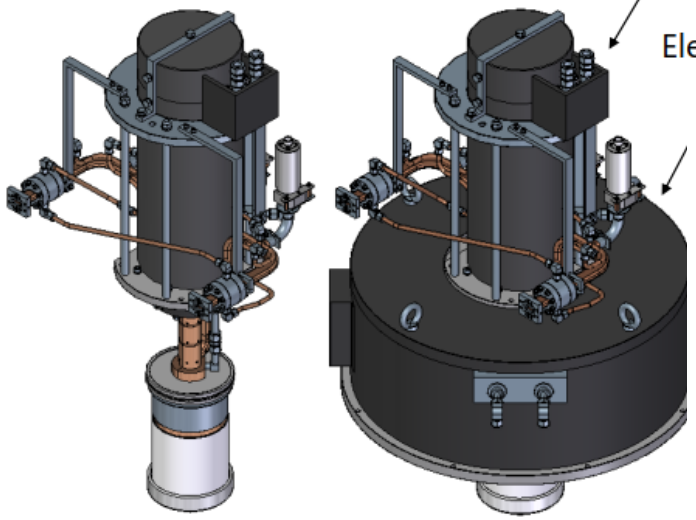
- Re-used solenoid.
- Re-used cathode
- Increased power gain (10 dB)

Prototype is in fabrication at Canon
To be shipped to CERN in 03.2022.

Retrofit design

8-10 MW	E37113 at factory	HEX COM_M (CERN/Canon)
Voltage, kV	154	154
Current, A	93	94
Frequency, GHz	11.994	11.994
Peak power, MW	6.2	8.16
Sat. gain, dB	49	58
Efficiency, %	42	57/ FCI
Life time, hours	30 000	30 000
Solenoidal magnetic field, T	0.35	0.4
RF circuit length, m	**0.127**	**0.127**

20-MW X-band Klystron (Recent on the market)



Parameter	Sim. Target	Design result
Beam voltage[kV]	265 (<290)	265
Beam current [A]	170.3 (<195)	170.3
Output power [MW]	>23	24.3
Efficiency [%]	>51	53.8
Drive power [W]	~120 (<400)	120
Max. electric field strength [kV/mm]	<64.5 (at 1.5 μs)	60.4
Stability	No reflected electrons	OK

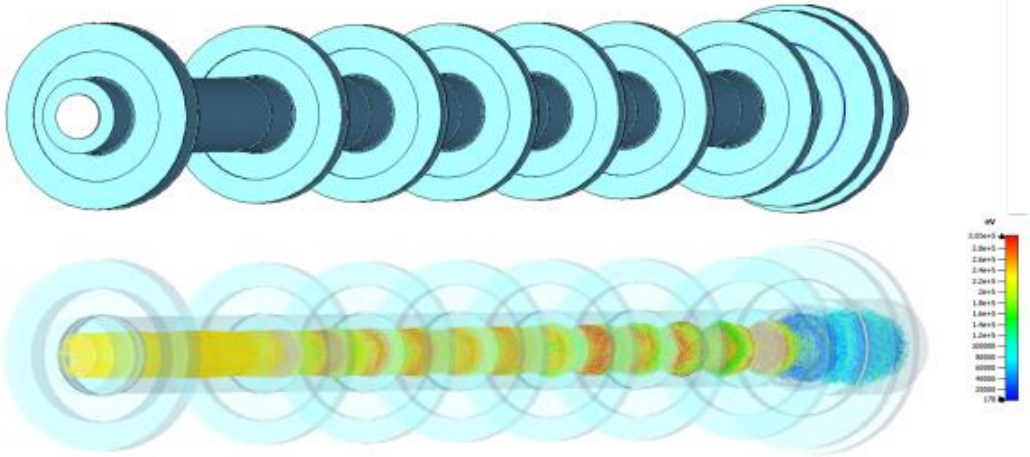
* Actual efficiency is estimated to be 46 - 48%.

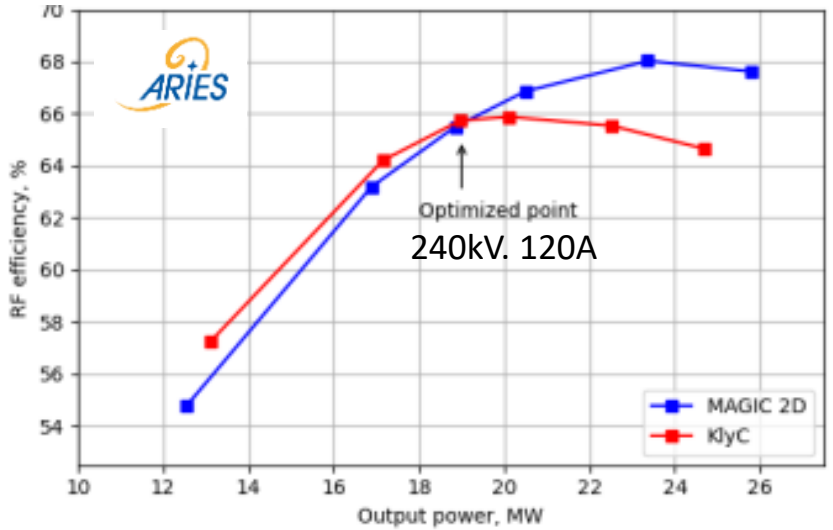
Canon

CANON ELECTRON TUBES & DEVICES CO., LTD.

Two tubes have been built and tested up to 20MW

20 MWX-band HE klystron design by CEA

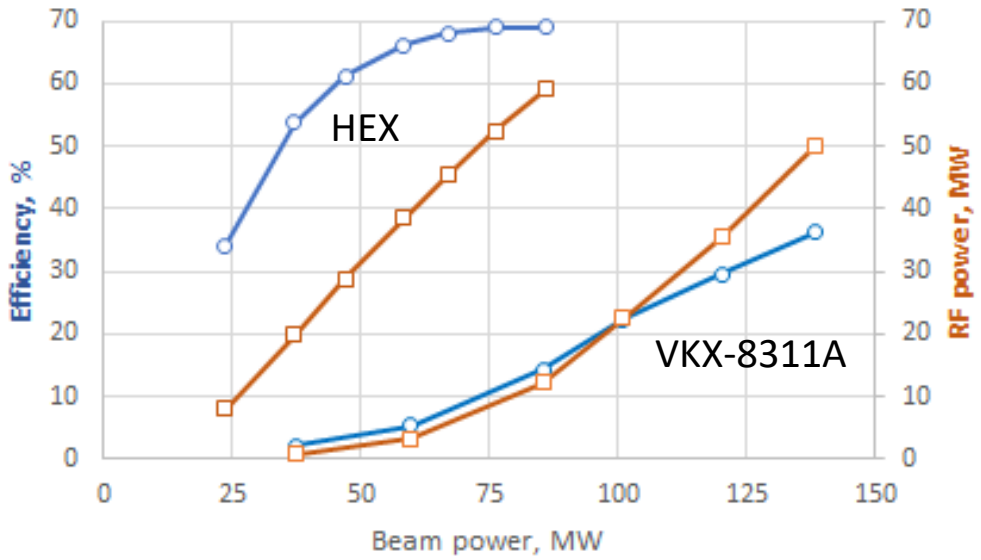




https://edms.cern.ch/ui/file/1817230/1.0/ARIES-Del-D4.2-Final.pdf

Retro-fit High Efficiency 50 MW, 12 GHz klystron (CERN/CPI).

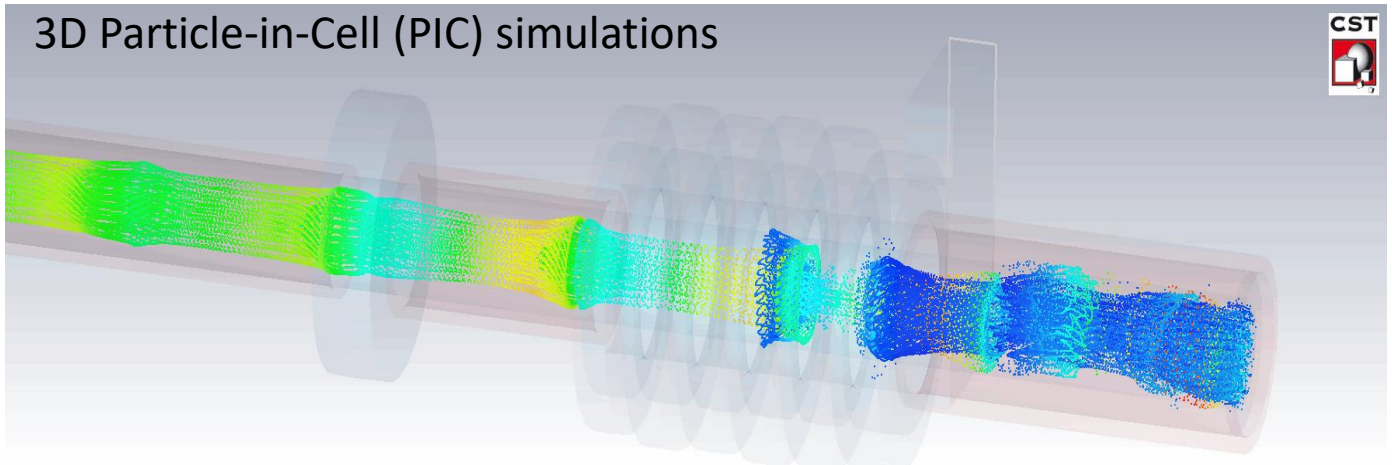
Saturated efficiency & RF power



- Re-used solenoid.
- Increased life time (> factor 2)
- Reduced modulator power (~ factor 2)
- Increased power gain (10 dB)
- Reduced solenoidal field

Prototype fabrication is under negotiation within CPI/INFN/CERN collaboration.

3D Particle-in-Cell (PIC) simulations



	VKX-8311A	HEX COM_M (CERN/CPI)
Voltage, kV	420	420
Current, A	322	204
Frequency, GHz	11.994	11.994
Peak power, MW	49	59
Sat. gain, dB	48	59
Efficiency, %	36.2	69
Life time, hours	30 000	85 000
Solenoidal magnetic field, T	0.6	0.37
RF circuit length, m	**0.316**	**0.316**

50 MW HE tube prototypes in BVERI (China). Recent communication.

For information

Beijing Vacuum Electronics Research Institute (BVERI)

Parameters	Specification	Tube 1801#	Tube 1802#	Tube 1803#
Frequency	11.424GHz	11.424GHz	11.424GHz	11.424GHz
Peak output power	≥50MW	51MW	50.4MW	50.8MW
Pulse repetition rate	120pps	50pps	50pps	50pps
RF pulse width	≥1.5μs	1.5μs	1.5μs	1.5μs
Gain	≥50dB	52.6dB	50.9dB	51.3dB
Efficiency	≥40%	55.6%	59.9%	56.3%
-3dB bandwidth	≥30MHz	38MHz	36MHz	33MHz
Beam voltage	450 KV~470KV	452kV	450kV	450kV
Beam current	≤250A	203A	187A	200.5A

- The prototyping is far from the final version. Large beam interception (partly explain efficiency spread) is not mitigated.
- In the test of 1802, the operating frequency (max efficiency) was reduced by 10MHz in 200 hours of operation at 50Hz (the cavities were chewed by the electron beam).
- BVERI is now planning to reduce operating voltage down to 400kV (higher perveance), simplify the RF circuit and increase magnetic field. All together (Igor's projection) the efficiency will be reduced down to about 50(+)%.

UHF/L-band HE klystrons
0.3MW - 24MW

Two-Stage Multi Beam Klystron (TS MBK) technology.

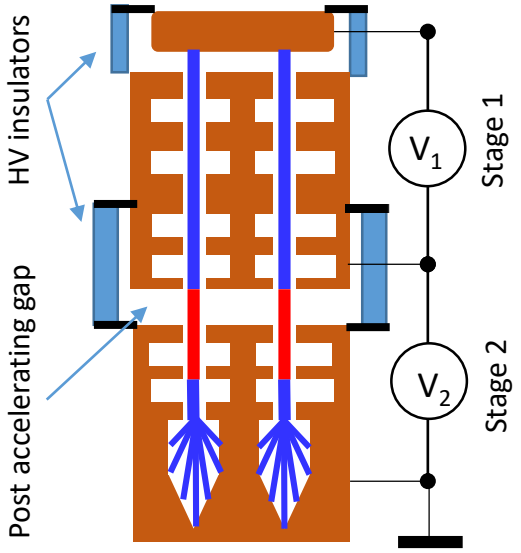
Specific features

1. Bunching at a low voltage (high perveance). Very **compact RF bunching circuit.**
2. Bunched beam acceleration and cooling (reducing $\Delta p/p$) along the short DC voltage post-accelerating gap.
3. Final power extraction from high voltage (low perveance) beam. **High efficiency.**

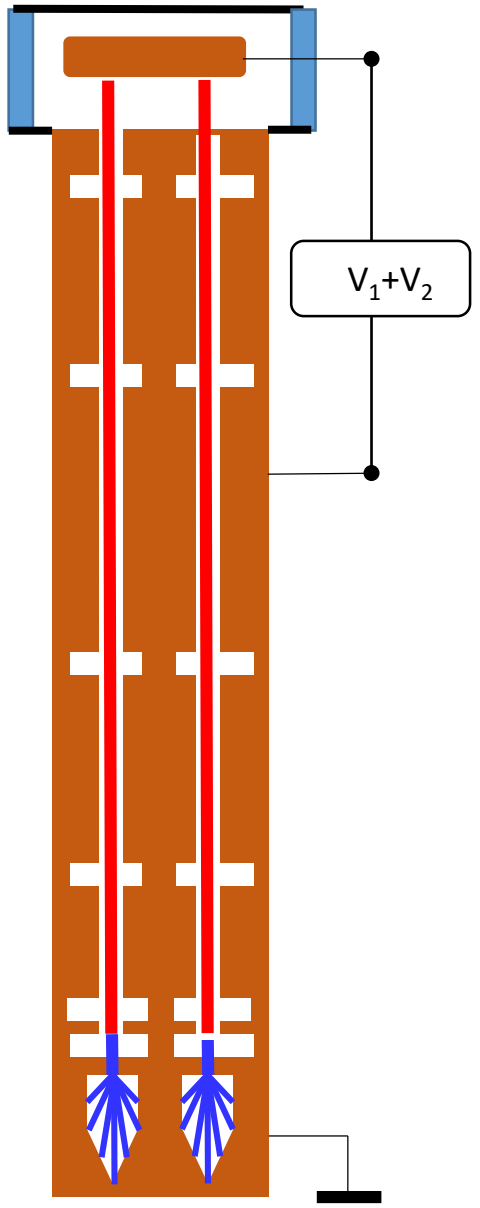
Additional advantages:

1. The second HV stage can be operated in DC mode. Thus simplifying the modulator topology (cost/volume) and increasing the modulator efficiency (in pulsed mode).
2. Simplified feedback for the first stage pulsed voltage. Improved klystron RF phase and amplitude stability.
3. Gap's accelerating DC voltage is a natural barrier for reflected electrons. Improved tube stability.

TS HE MBK
Efficiency 85%

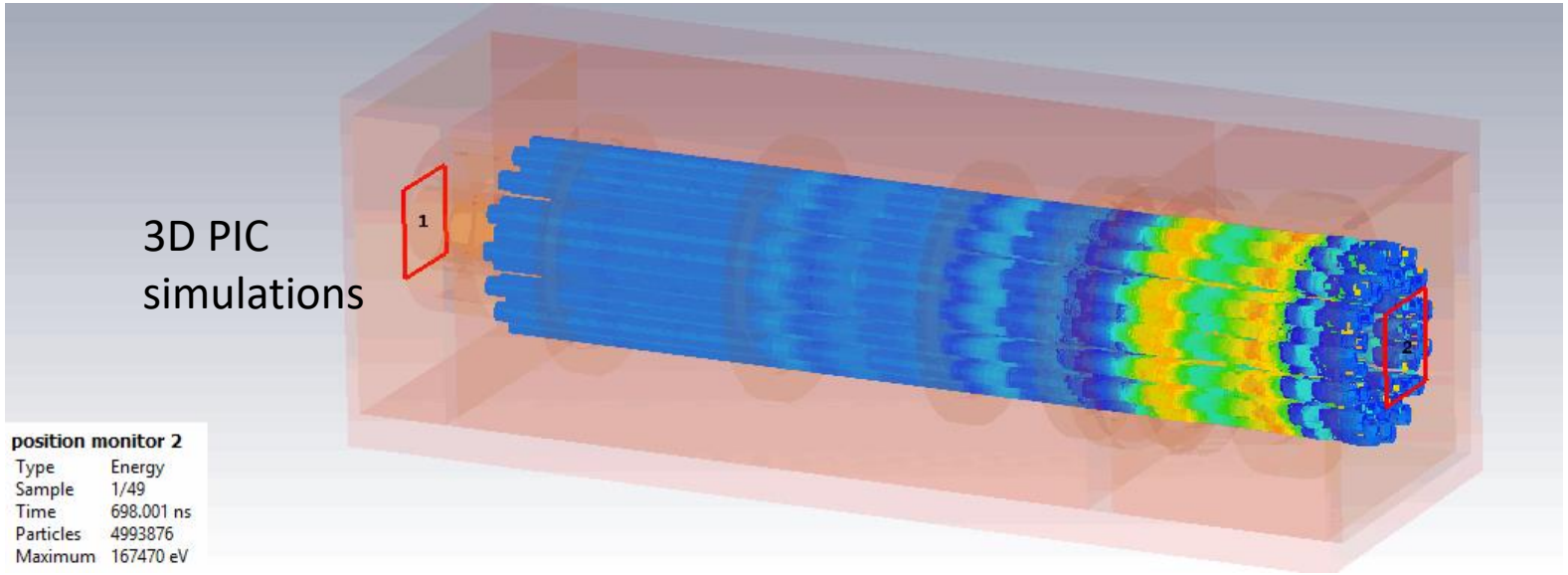


Commercial HE MBK
Efficiency 70%



High Efficiency 24 MW, 1 GHz, CLIC TS MBK performance summary (PIC CTS/3D)

3D PIC simulations



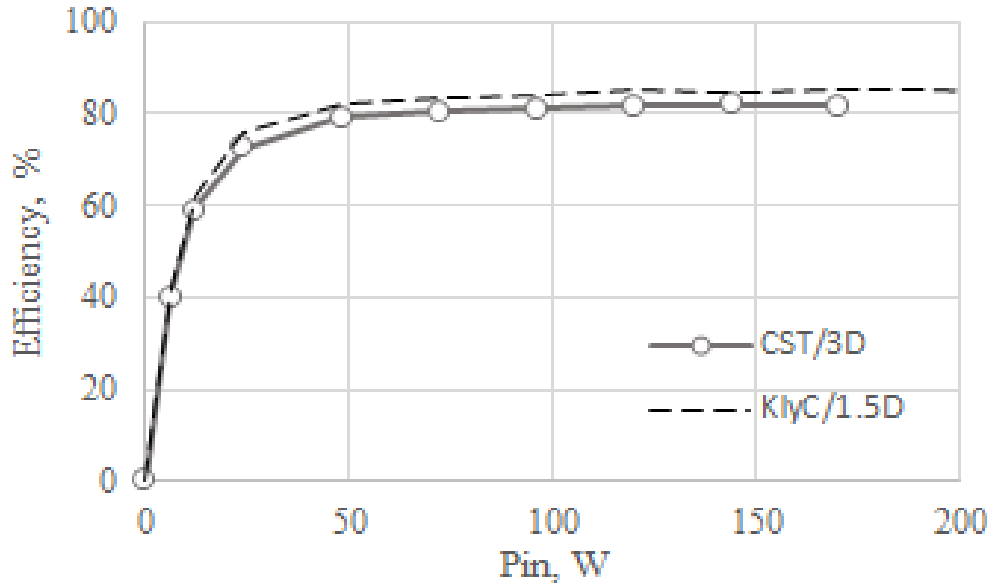
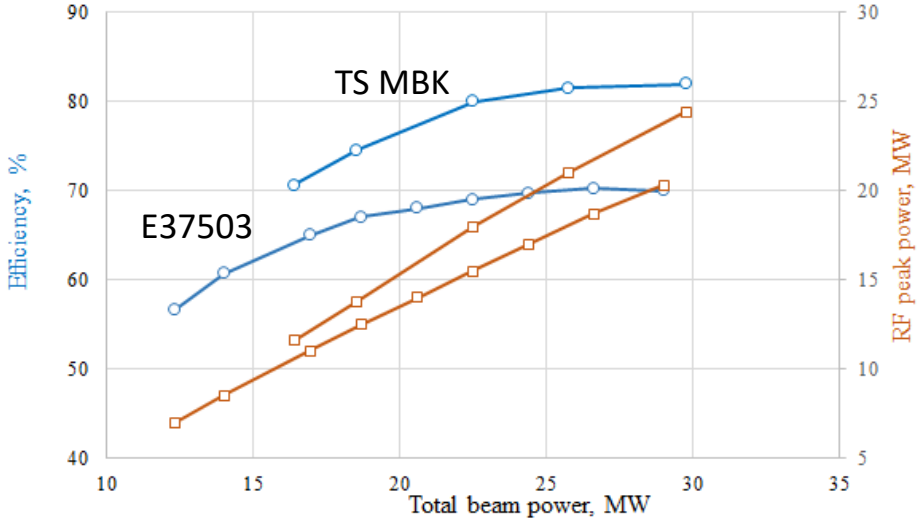


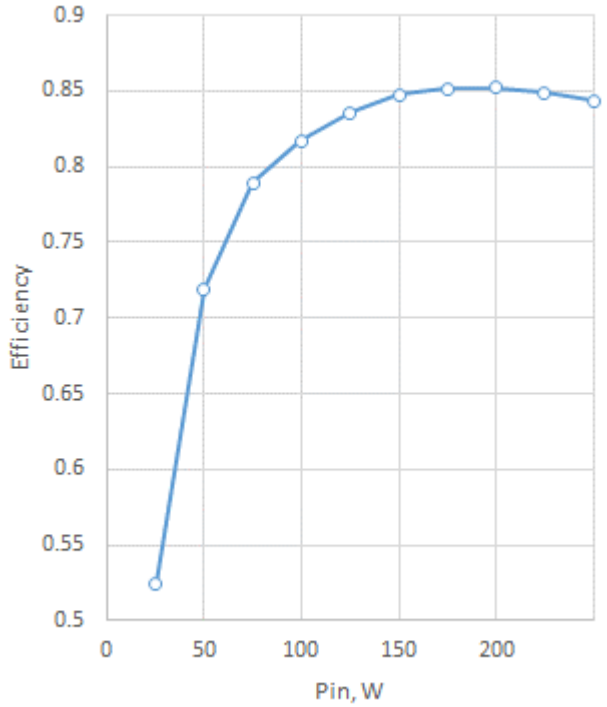
TABLE I. DESIGN AND SIMULATED PARAMETERS (CST/3D) OF THE CLIC TS MBK AND CANON MBK E3750 CATALOGUE DATA

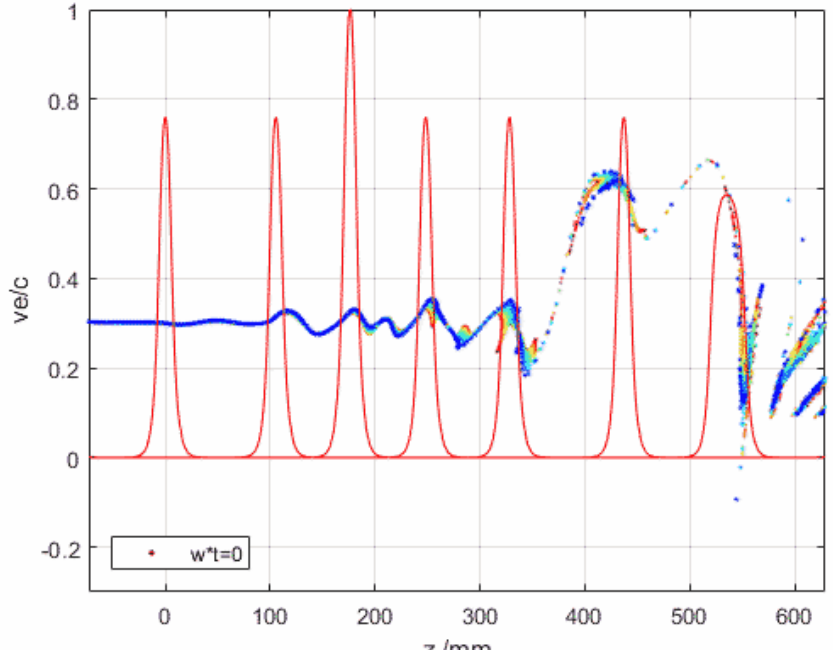
Parameter	TS MBK	E37503	Unit
Operating frequency	1000	1000	MHz
Voltage at the 1st stage	25	160	kV
Voltage at the 2nd stage	140		
Total beam current	212	180	A
Number of beamlets	30	6	
Number of cavities	6	6	
Perveance at the 1st stage	1.77	0.47	$\mu A/V^{3/2}$
Perveance at the 2nd stage	0.133		
Output RF power	24.1	20	MW
Saturated power gain	52	54	dB
Saturated efficiency	82	70	%
Length of RF circuit	900	1500	mm

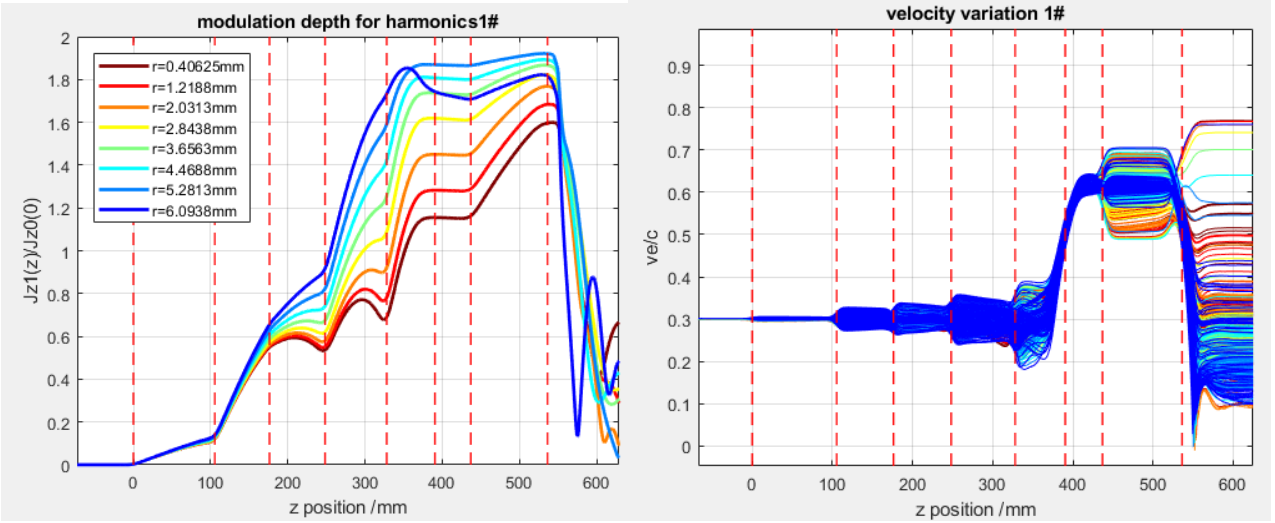


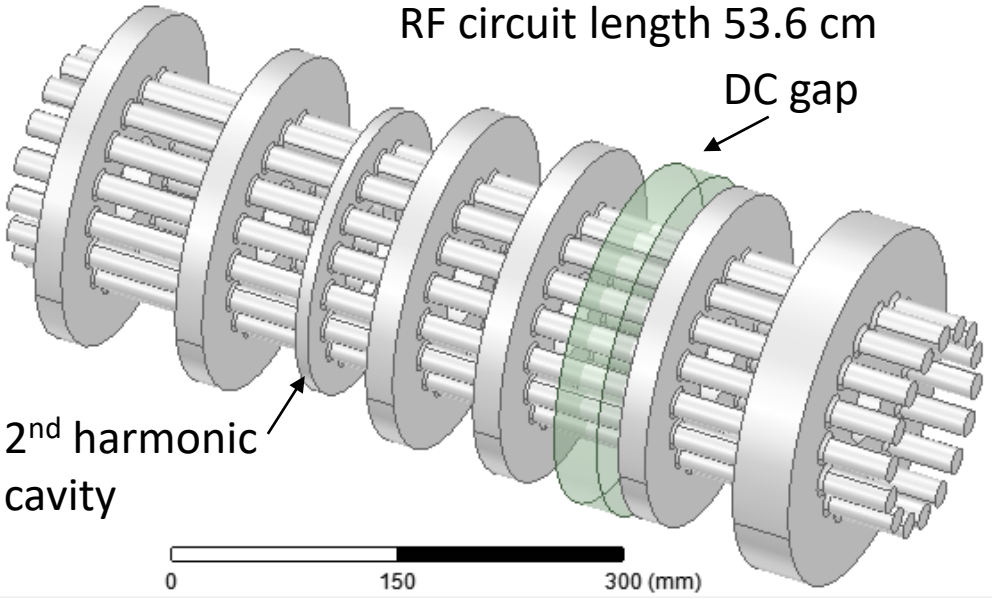
High Efficiency 10 MW, 1.3 GHz, ILC TS MBK (scaled from TS CLIC MBK+2nd harmonic)

Parameter	TS MBK	E37536	Unit
Operating frequency	1300	1300	MHz
Voltage at the 1st stage	25	118.8	kV
Voltage at the 2nd stage	140		
Total beam current	88	129.5	A
Number of beamlets	16	6	
Number of cavities	7	6	
Perveance at the 1st stage	1.68	0.53	μA/V$^{3/2}$
Perveance at the 2nd stage	0.105		
Output RF power	**10.5**	**10**	MW
Saturated power gain	47.2	48.2	dB
Saturated efficiency	**85**	**65**	%
Length of RF circuit	536	---	mm









I. Syratchev, CLIC PM #41, 13.12.2021