CLICWEEK2019
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The new concept of the compact and efficient 24 MW MBK L-band klystron for the CLIC drive beam accelerator(s)

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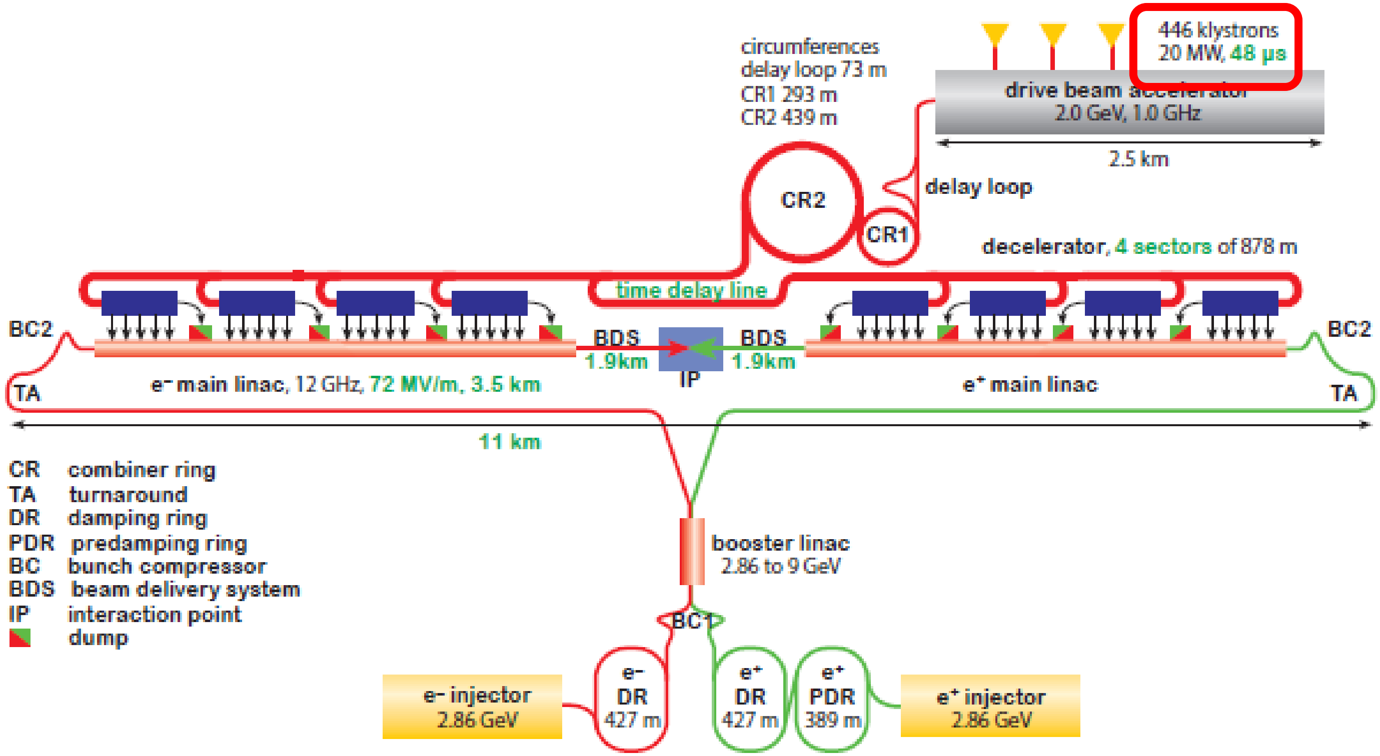
The CLIC two-beam 380 GeV layout



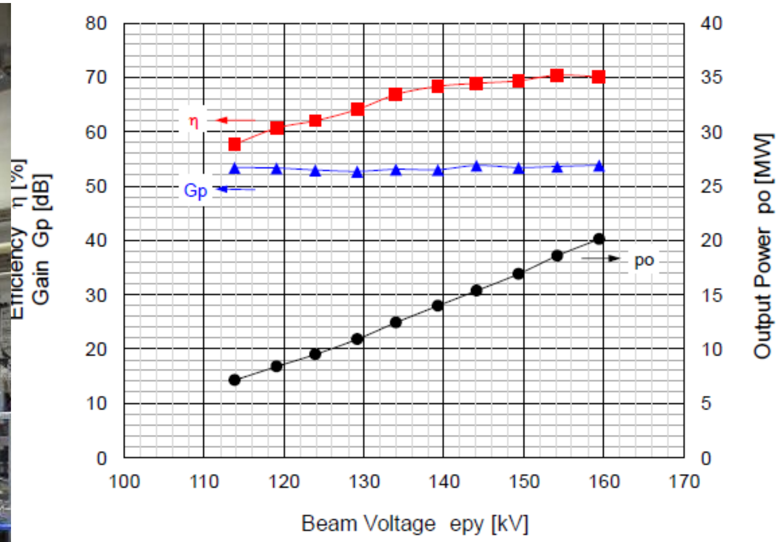
- For the CLIC two-beam 3 TeV option, the new high efficiency klystron technology has a potential to save (5khour/year, 50 €/MWh) in 10 years **152 M€**, and, 18M€ for 380 GeV.
- Increasing the peak power of the individual tube by 20% will proportionally reduce the investment cost of DBA.

Technology	Existing	New
Klystron, %	70	80
Modulator, %	90	98

CLIC RF power budget (20 MW tubes at 50 Hz)

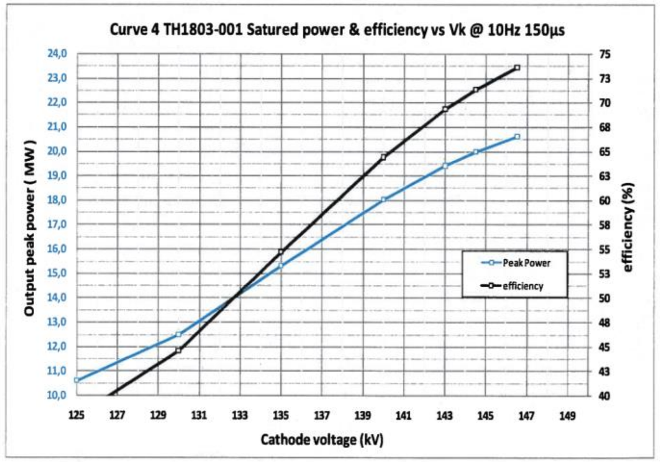
E cm	N klystrons	T pulse, μs	Power peak, GW	Power av., MW	P AC (1), MW	P AC (2), MW
3 TeV	1230	150	24.6	184.5	**296**	**235**
380 GeV	446	50	8.92	22.3	35.8	28.5

The two 20MW MBK CLIC L-band klystron prototypes have been built and tested in industry.



F=	999,5 MHz
P max=	21 MW
T =	150 msec
V=	159.4 kV
I total =	180 A
Eff.=	71.5 % (76%/design)
uP=	0.47 $\mu AxV^{-3/2}$/beam
Gain =	53.9 dB

Tested to specification

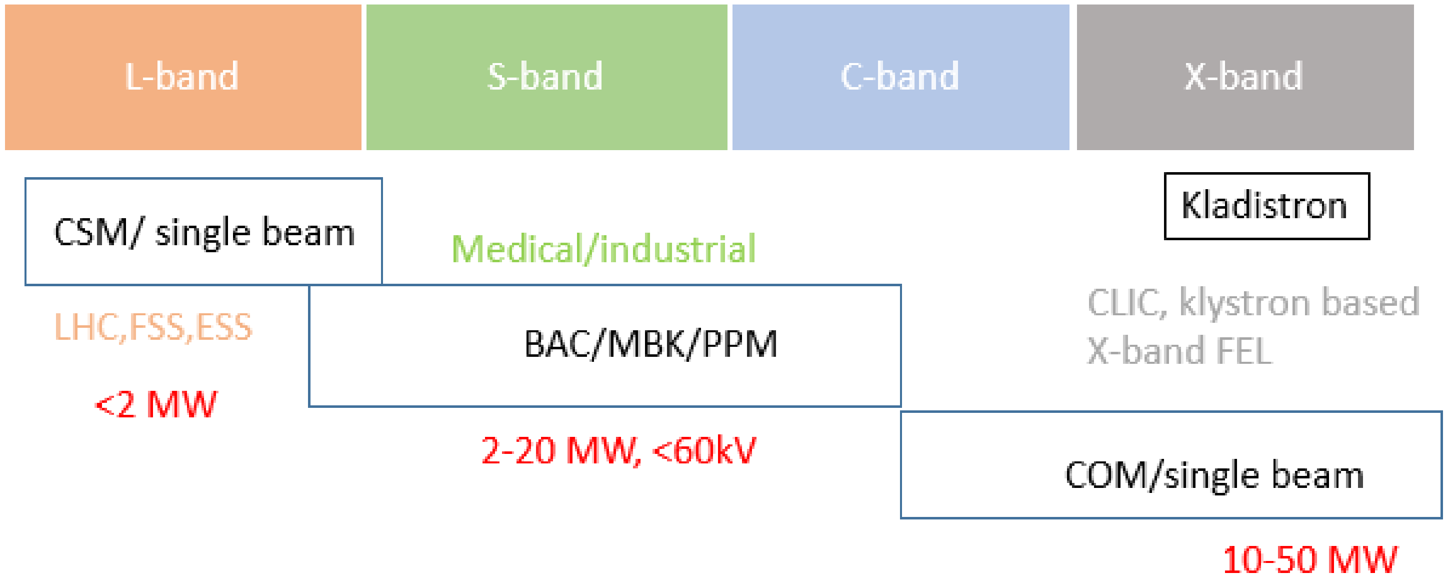


F=	999,5 MHz
P max =	21 MW
PL =	150 msec
V=	146.5 kV
I=	191 A
Eff. =	73.5 % (76%/design)
G=	0.341 $\mu AxV^{-3/2}$/beam
Gain =	51.5 dB

- Beam losses in the output cavity (max 10 Hz rep rate)
- Large (30%) power asymmetry between output ports
- Instability regions at input power below saturation.

80% efficiency. Challenges for the CLIC MBK.

The new klystron bunching technologies allow for the high RF power production efficiency. The choice of particular technology may drive the applicable frequency range and multi-beam options

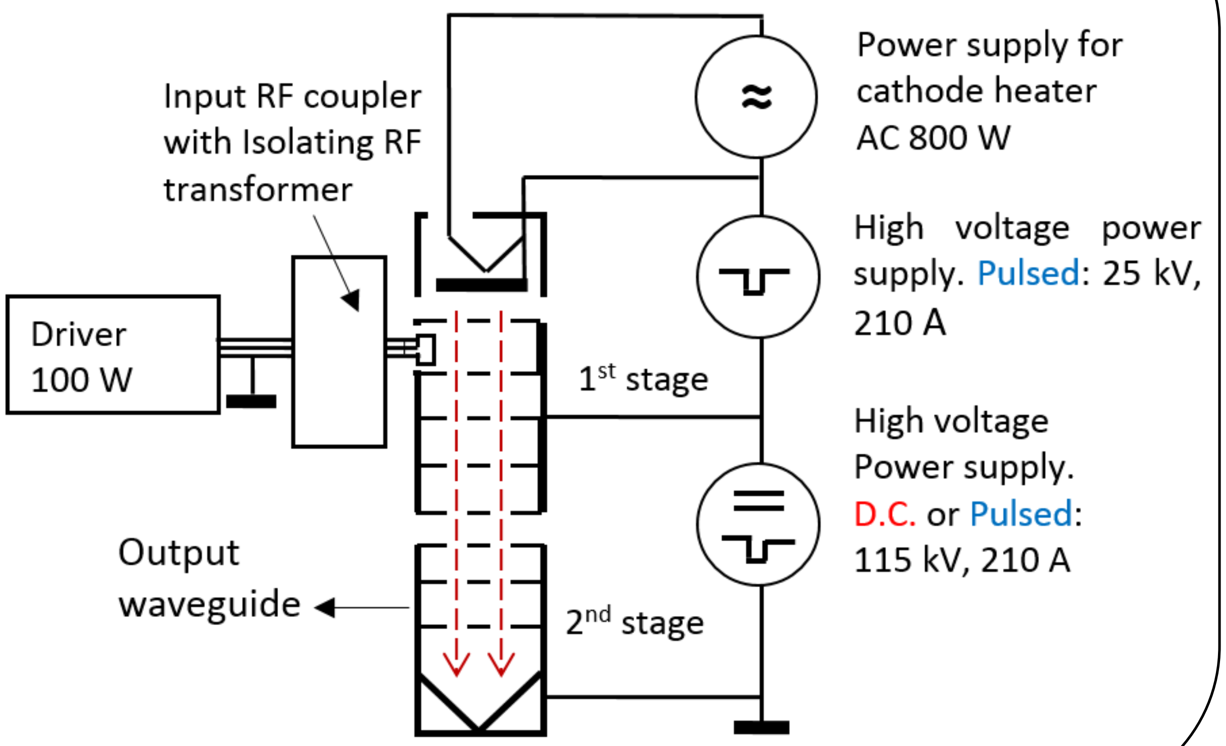


None of these technologies can be directly adopted for the CLIC MBK high power L-band tube because of technical challenges and associated cost.

- Core Oscillation Method (**COM**) requires very long (almost 5 m) bunching RF circuit.
- Bunching Alignment and Collection (**BAC**) allows to reduce by factor 2.5 the tube length, but it requires 2.5 times more RF cavities (~20 cavities in total).
- Core Stabilization Method (**CSM**) is optimal for L-band (1.5m long RF circuit), but it employs 3rd harmonic cavity, which is impractical for the MBK RF cavities topology.

The new concept of L-band MBK for CLIC with two high voltage stages

Electric circuit of the CLIC MBK with two HV stages



Innovative 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 short DC voltage 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) and increasing the modulator efficiency (transients).
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.

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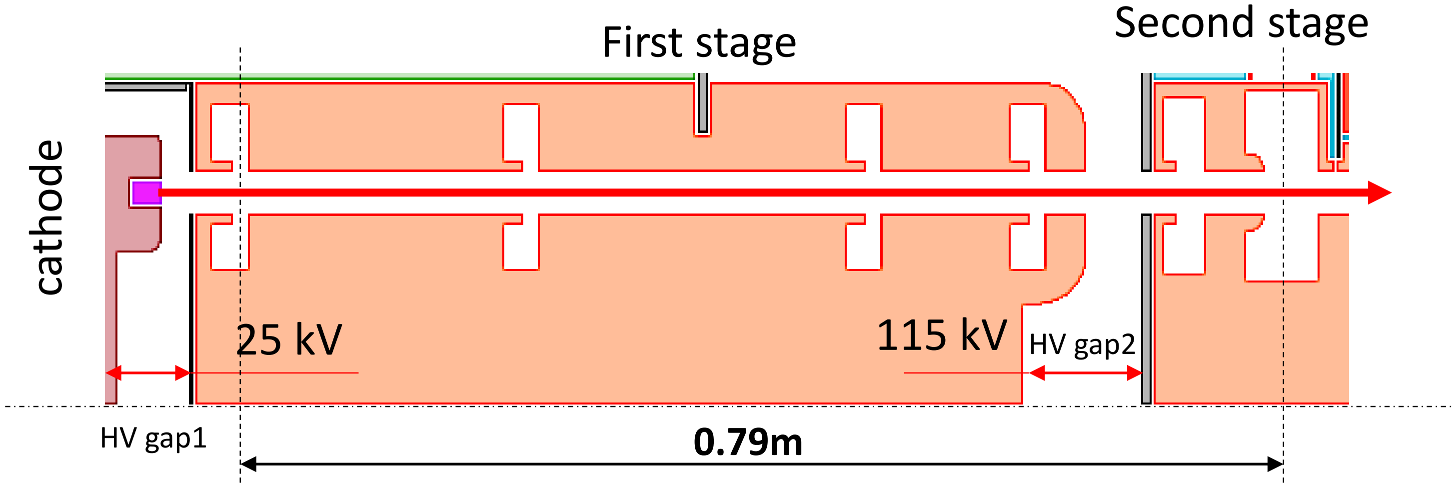
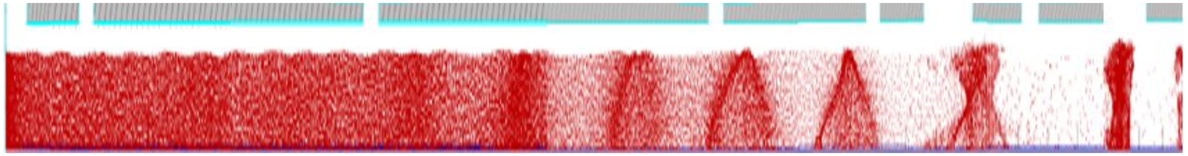
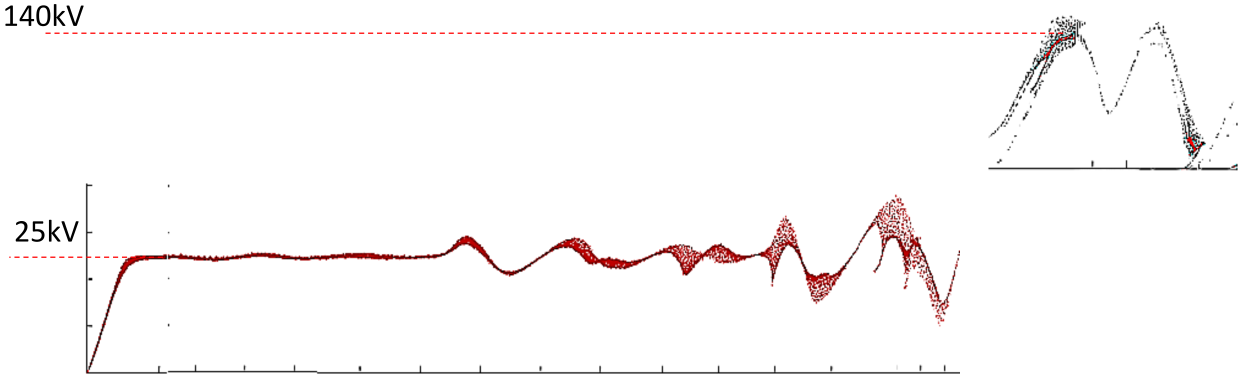
Prove of principle in the PIC (MAGIC/2D) simulations.

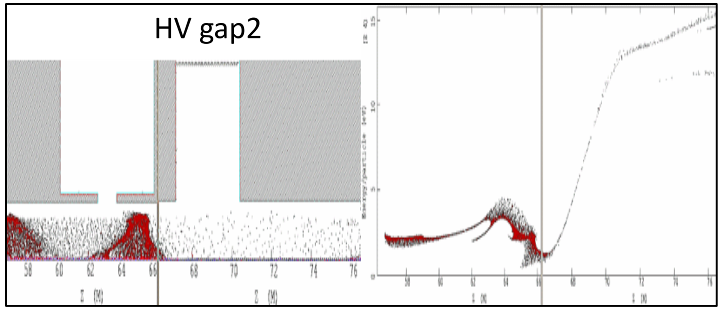
6 cavities MBK/DS klystron layout



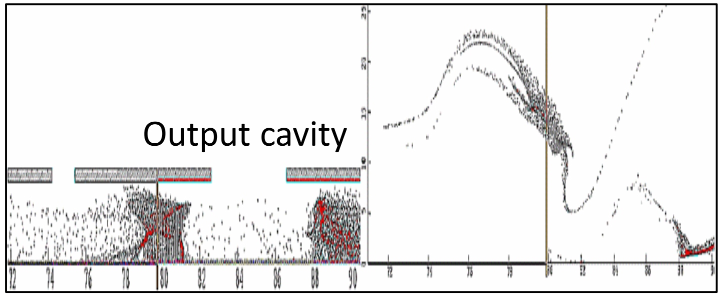




Bunched beam acceleration and cooling



Bunched beam deceleration

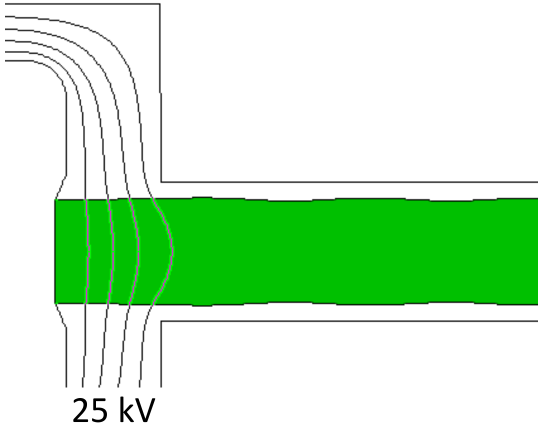


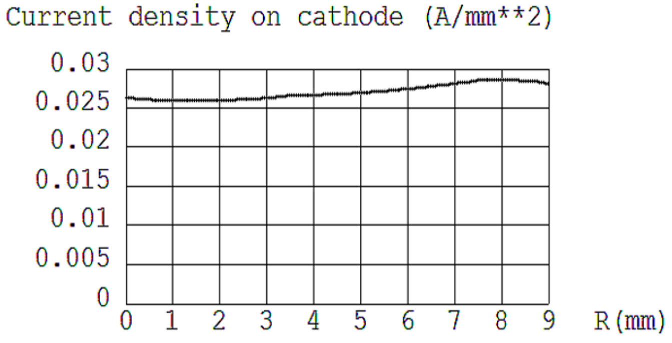
The electron efficiency 84%.

Total efficiency ~83%.

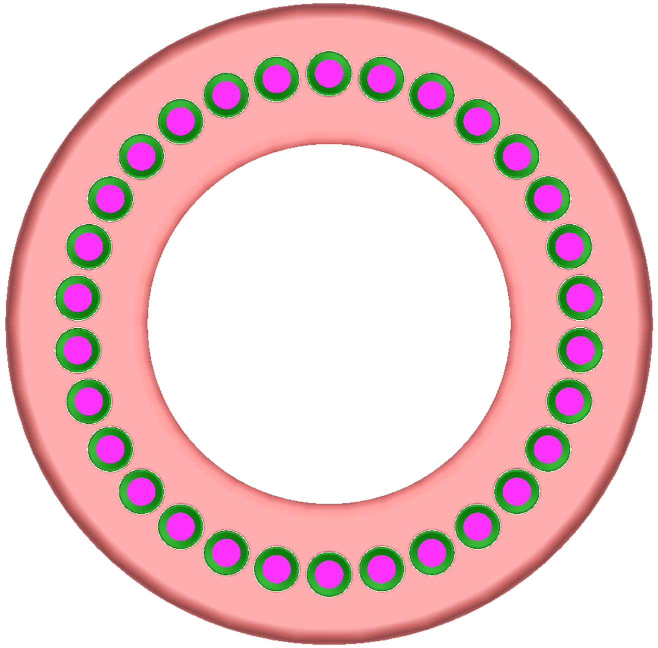
Multi-beam cathode for CLIC MBK/DS

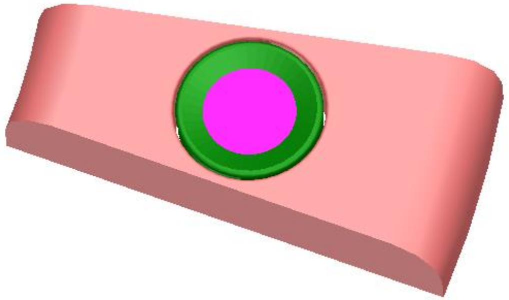
1. The simple (cost) magnetized gun optics with surface current density below 3A/cm^2 (life time ~10^5 hours) provides the most compact packing arrangement of the individual beamlets (no beam compression) together with high beam quality in the drift channels





2. For the fixed perveance, the total number of beamlets is driven by peak RF power (24 MW) operating voltage (140 kV) and expected efficiency (84%). The suggested number Nb=30.





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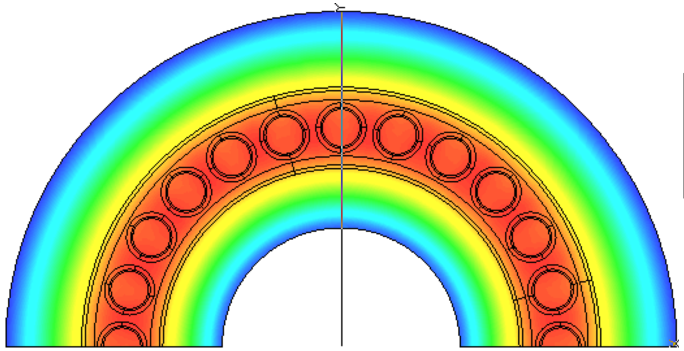
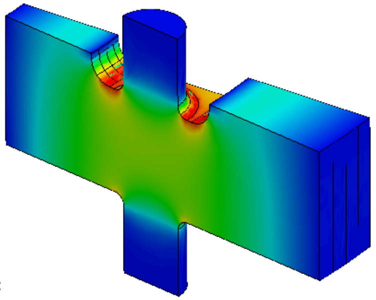
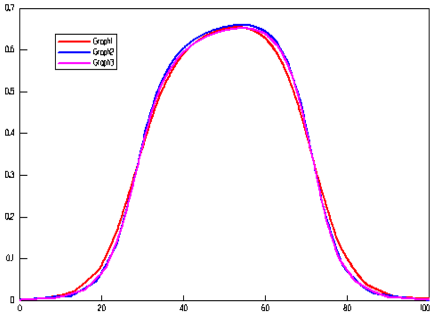
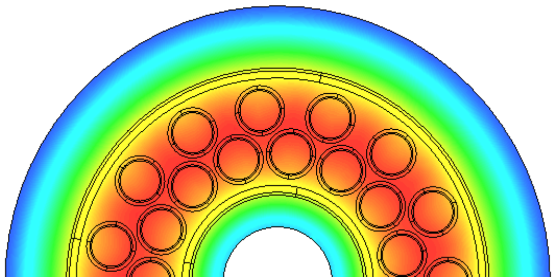
RF cavities for the CLIC MBK/DS

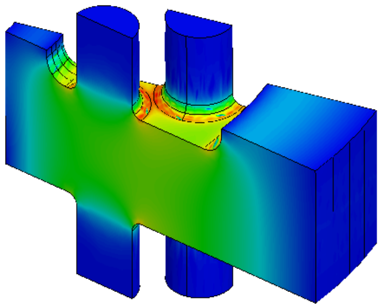
Two types of bunching cavities for the different beamlets arrangement

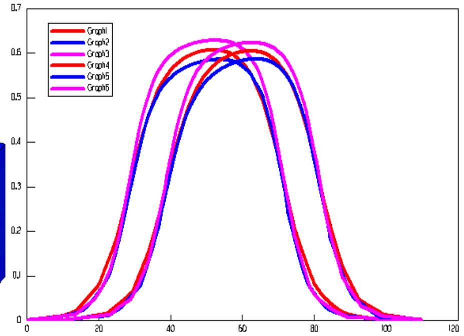




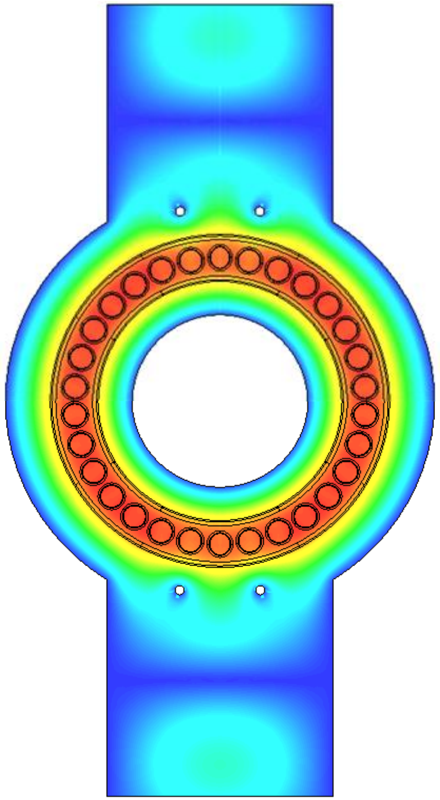




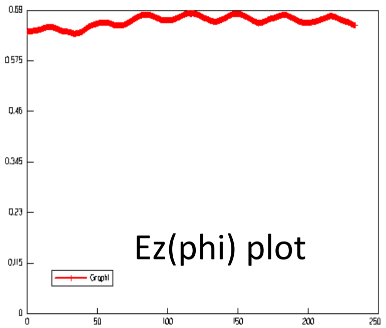




Output cavity



¼ of geometry



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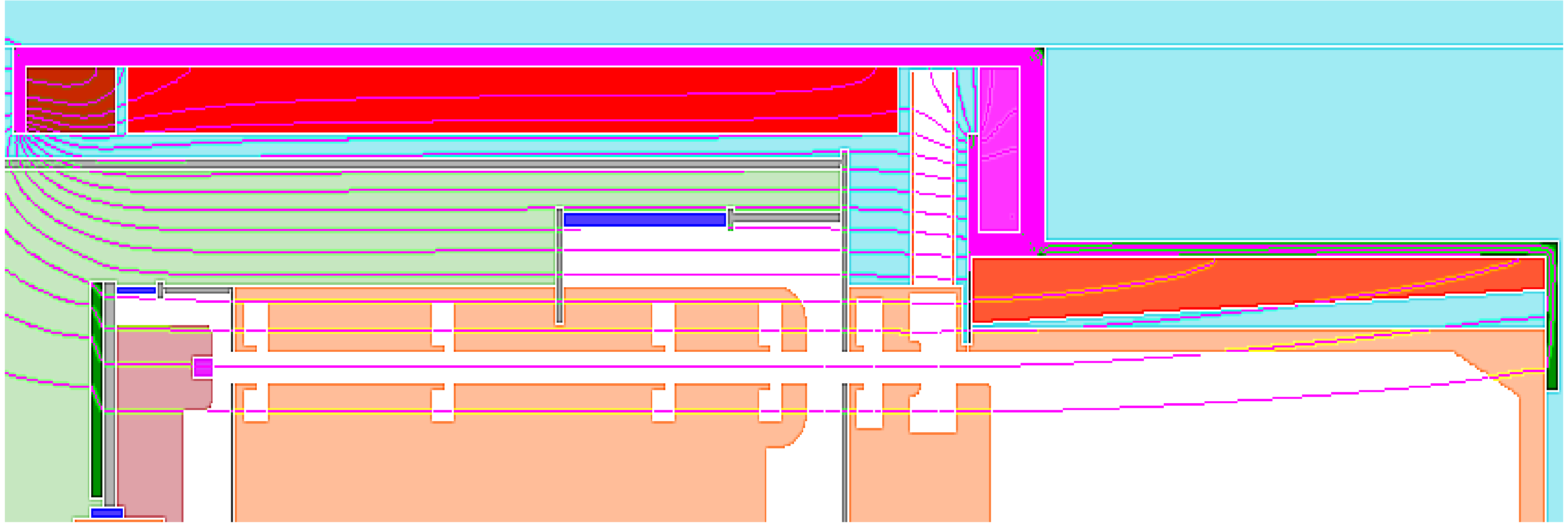
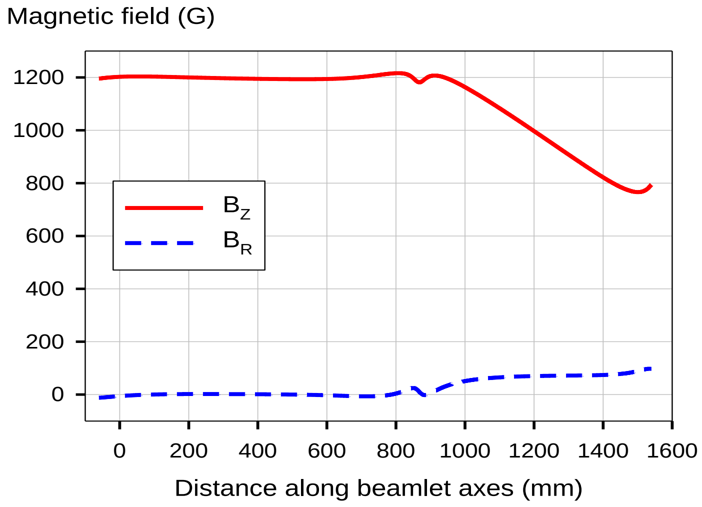
Magnetic circuit(s) for the CLIC MBK/DS



Optimized magnetic field profile in the tube



Magnetic circuit should provide homogeneous magnetic field along the cathode and interaction region and help to minimize thermal loading in the collector.

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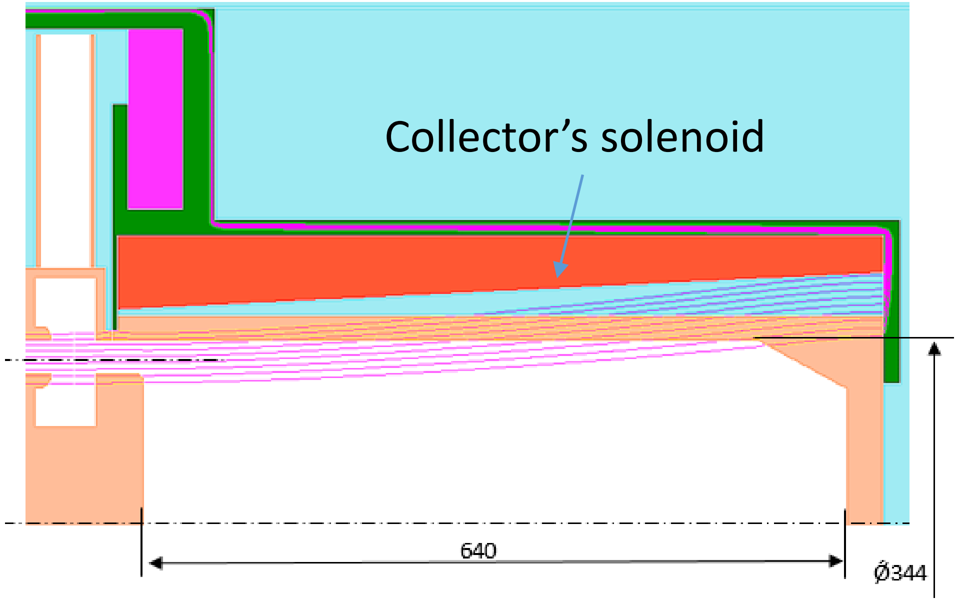
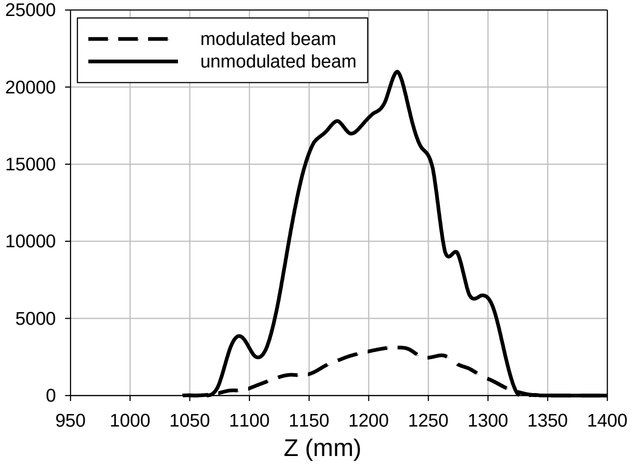
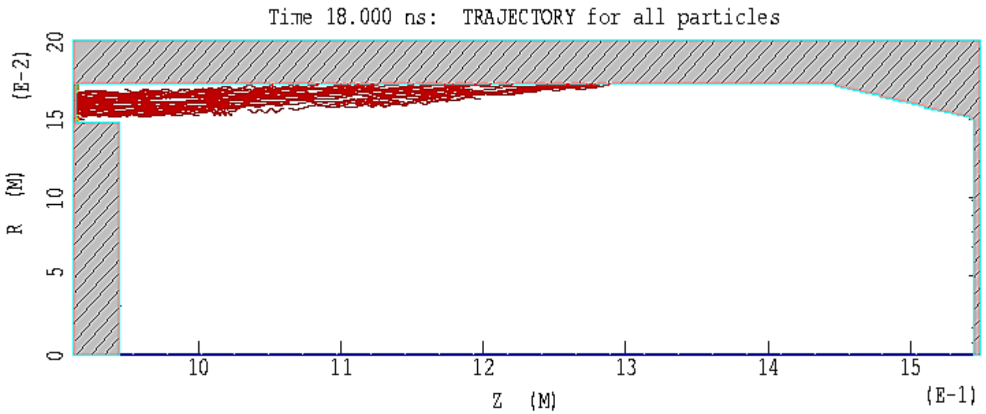
Proposed common collector for the CLIC MBK/DS



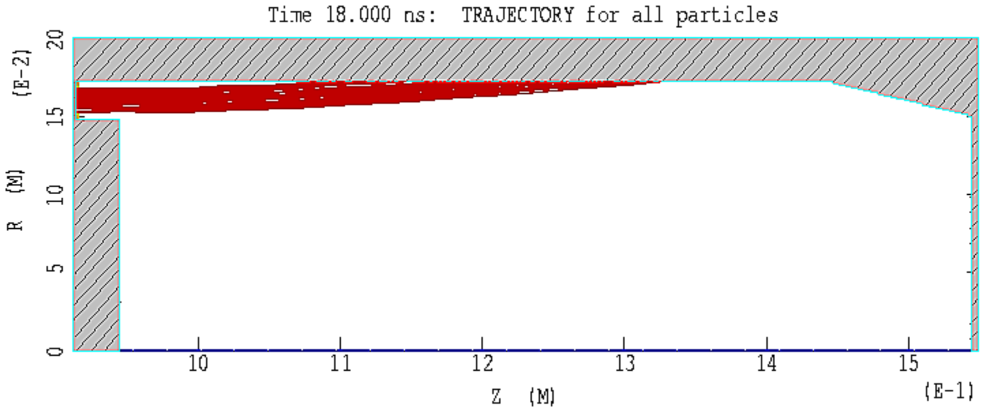
Peak loading W/cm²



MAGIC simulations, RF mode

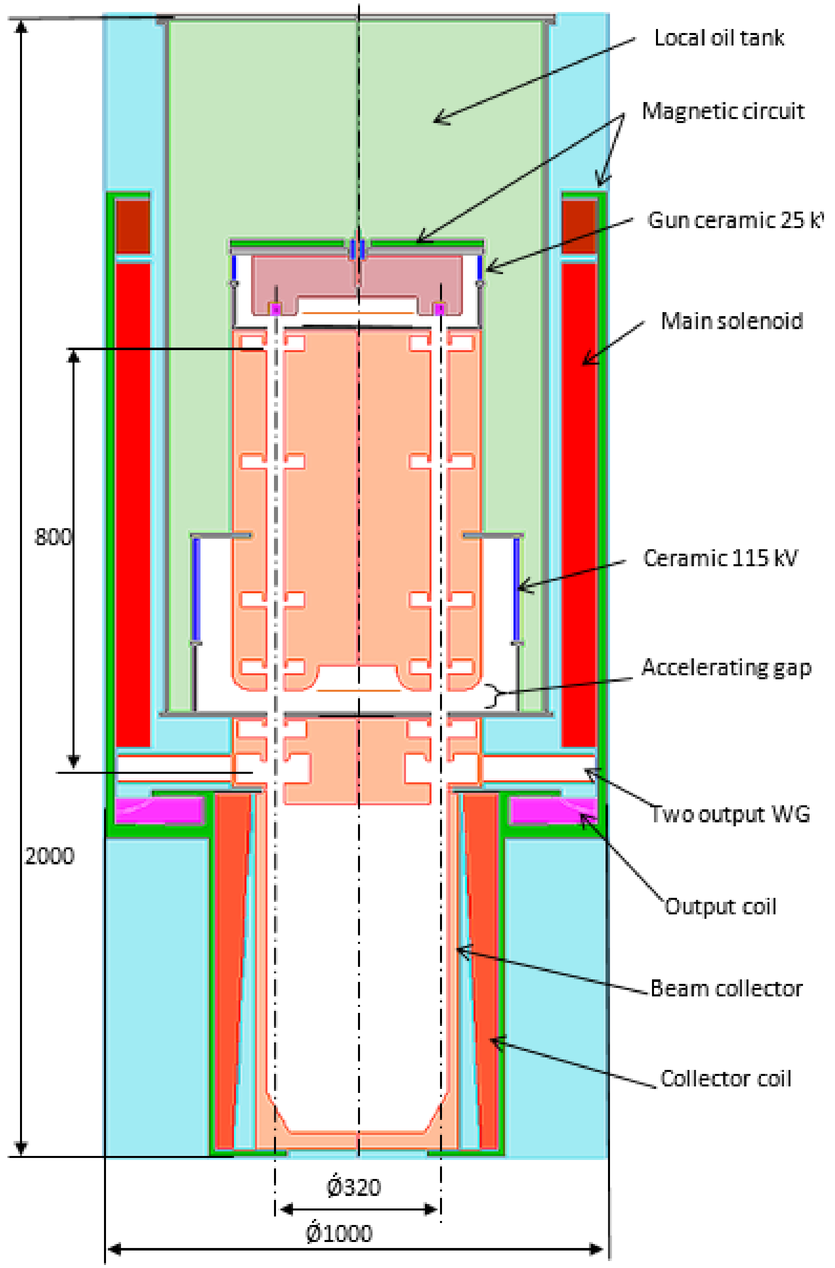


MAGIC simulations, diode mode



For averaged peak loading of 100 W/cm^2 in diode mode, the average beam power is 150 kW (CLIC specification).

CLIC MBK/DS. Summary.



Operating frequency	1000	MHz
Beam voltage of the 1st stage	25	kV
Beam voltage of the 2nd stage	140	kV
Total beam current	210	A
Number of beamlets	30	
Number of cavities	6	
Beamlet perveance of the 1st stage	1.77	$\mu A/V^{3/2}$
Beamlet perveance of the 2st stage	0.134	$\mu A/V^{3/2}$
Output RF power	24	MW
Saturated gain	54	dB
Saturated efficiency	84	%
Efficiency of the output circuit	99.4	%
Peak electric field in the gun	35	kV/cm
Peak electric field in accelerating gap	40	kV/cm
Peak electric field in output cavity	67	kV/cm
Focusing magnetic field	1200	G
Solenoid power	~15	kW
Heater power of cathode	~800	W
Average cathode loading	2.7	A/cm^2
Diameter of beamlet cathode	18	mm
Drift tube diameter	24	mm
Length of RF part	790	mm
Length of tube with local oil tank	2000	mcm
Collector power	150	kW
Peak collector loading	100	W/cm^2
Duty factor for unmodulated beam	0.005	

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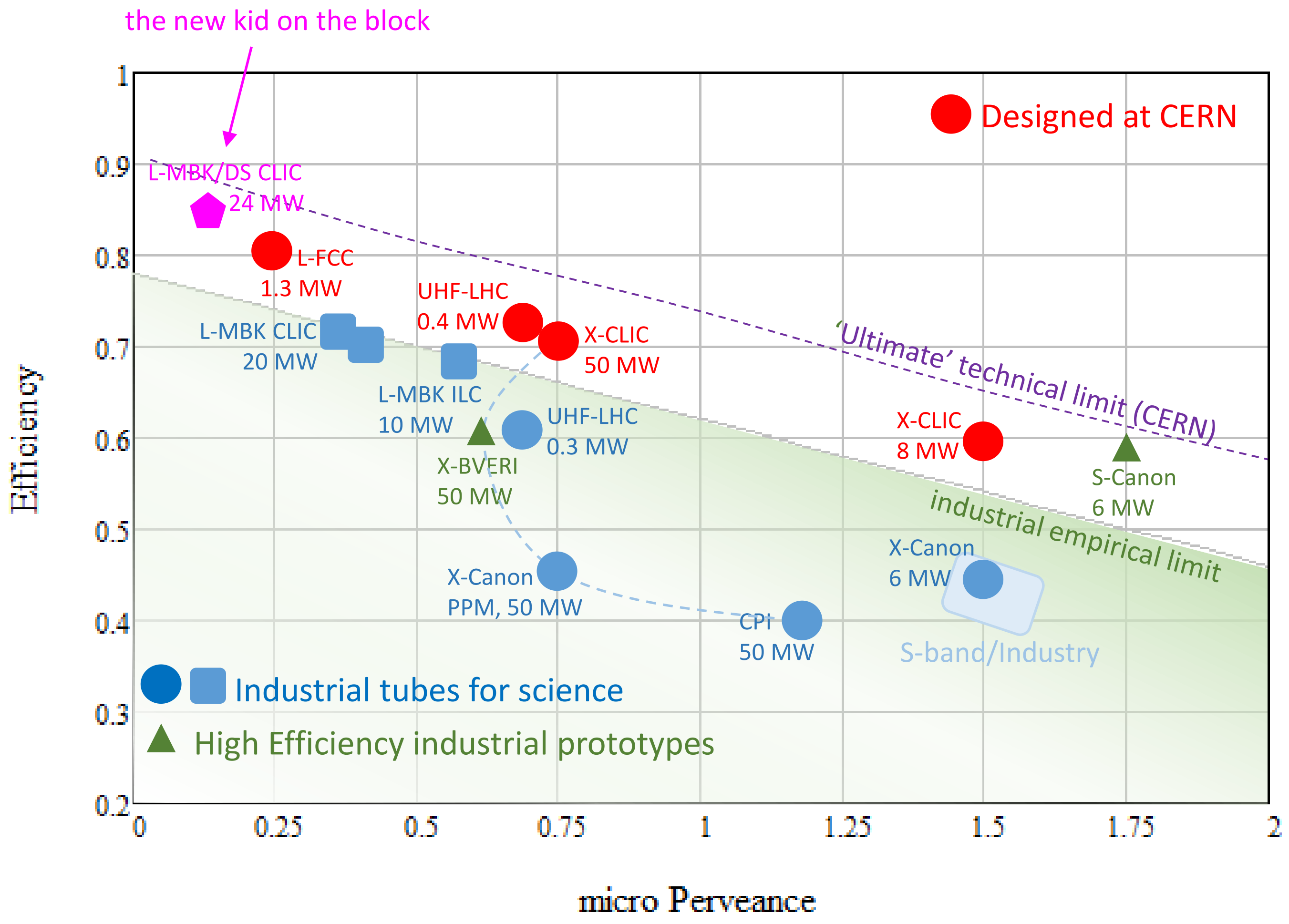
Updated klystron's efficiency/perveance map



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