Design study of the high efficiency L-band Klystrons at CERN.

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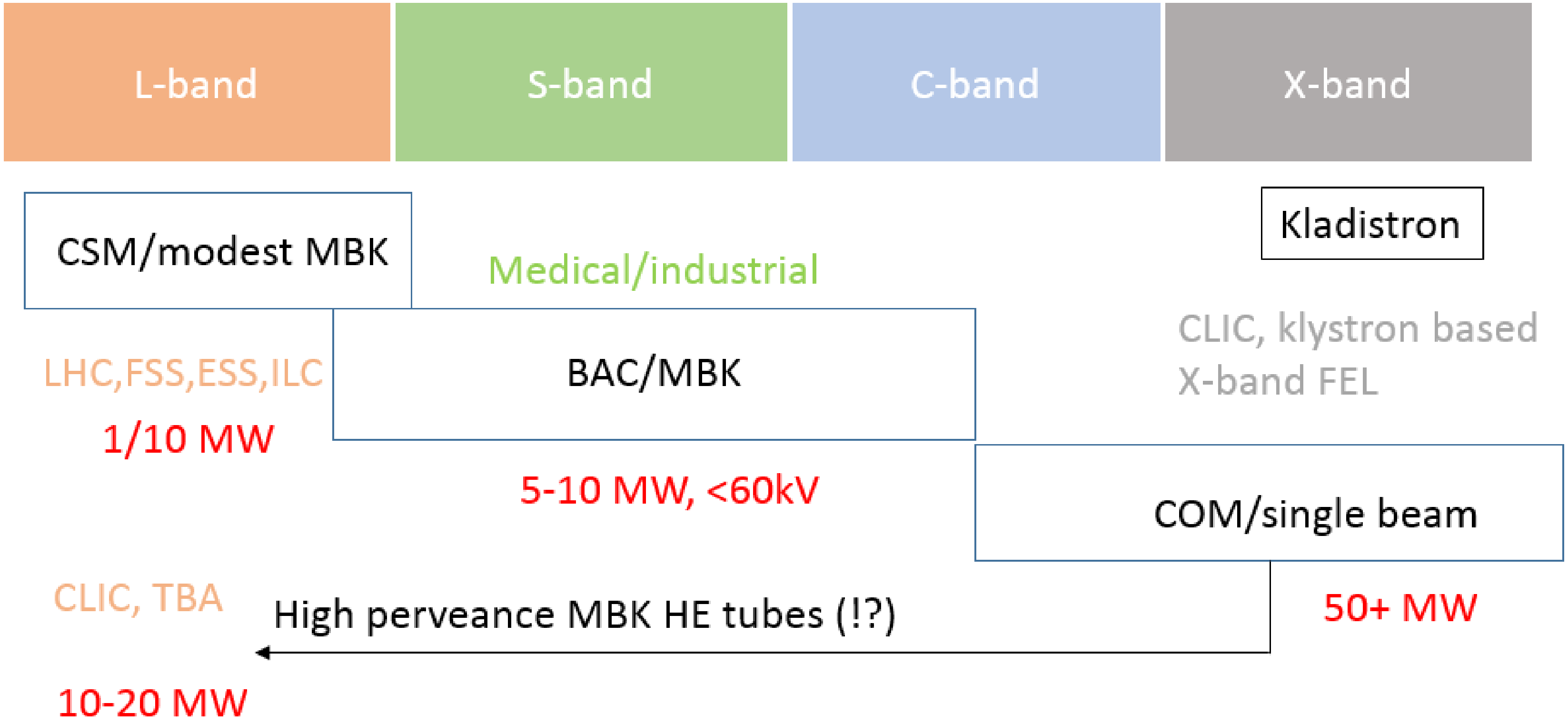
1. The new klystron bunching technologies have been developed recently at CERN within HEIKA collaboration. These technologies allow to boost the klystron efficiency up to 80%.
2. The choice of bunching technology may drive the applicable frequency range, peak power and multi-beam options (cost/performance):



Computer tool for the klystron simulations.

1. The success of klystron development strongly depends on availability of specialized klystron computer codes.
2. A number of such codes have been developed in the past, unfortunately, the accurate and efficient 2D large-signal codes are proprietary and are not freely available to the wide klystron community.
3. Recently the 1D/2D klystron code KlyC has been developed at CERN as an attempt to bridge the gap between fast, but approximate 1D models and time/resources consuming PIC codes.

KlyC 1D/2D potentials:

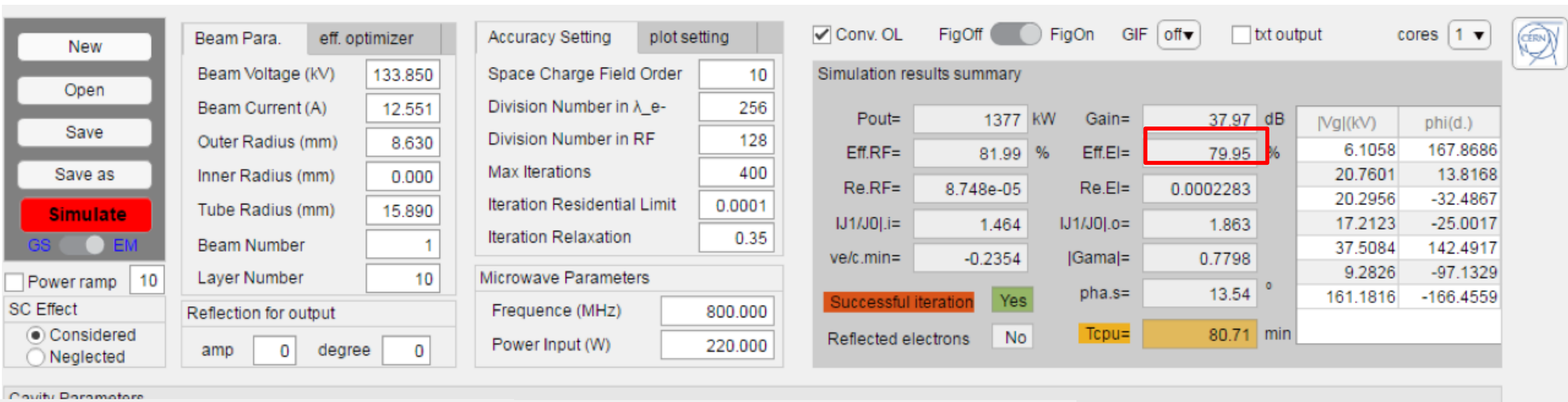
1. Free access for the klystron community.
2. Efficiency, much faster (~1/1000) simulation than PIC
3. Precision, 2D simulation are supported ('frozen' beam)
4. Diversity, possible extension to other Klystron's topologies (Multi-gap, Multi-beam, Traveling wave structure etc…)
5. Flexibility, can be fully adapted for special needs (partitioning, bunched beam generation etc.) and versatile output data interface.

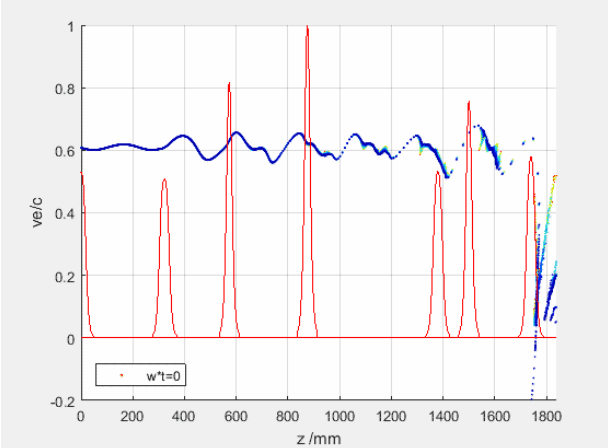
CSM L-band (0.8 GHz) klystron for FCC e^+e^-.

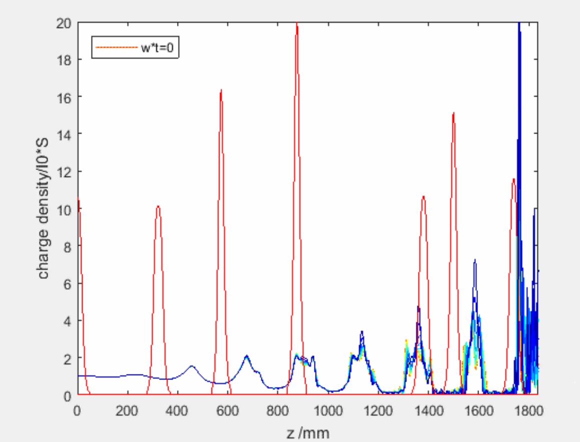
For the FCC e^+e^- option, the klystron efficiency is very important issue, as RF power station has to compensate 50 MW beam power losses in CW.

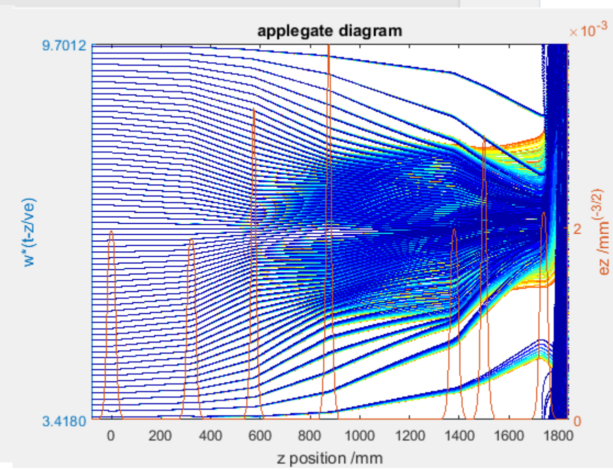
Such a klystron with efficiency 80% and 1.3 MW peak power has been developed at CERN.

Core Stabilization Method (CSM) has been chosen to ensure compact (1.7 m) RF circuit and high efficiency.

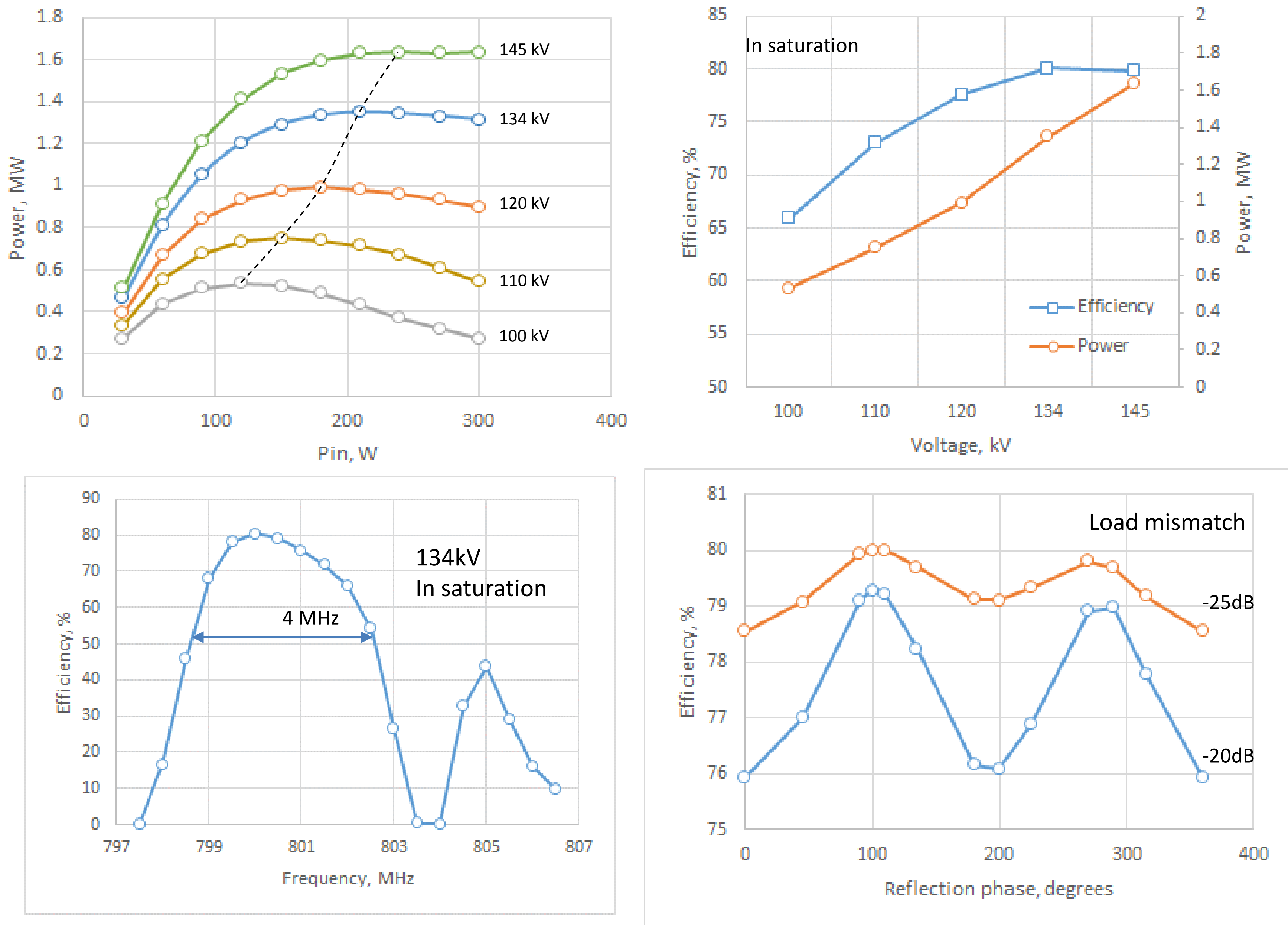




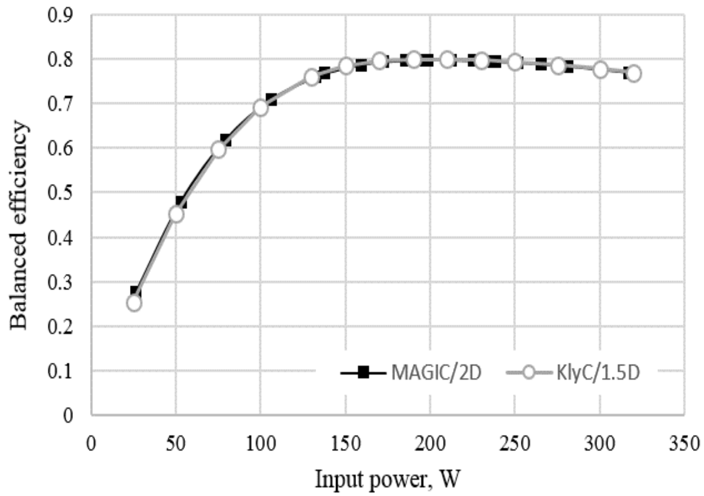


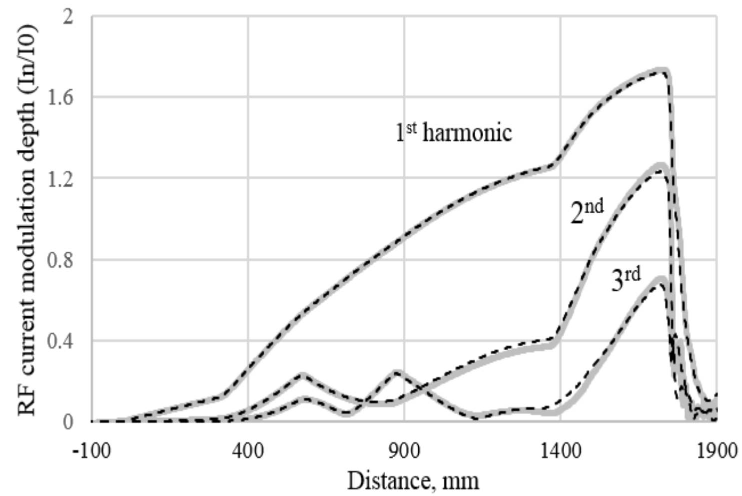


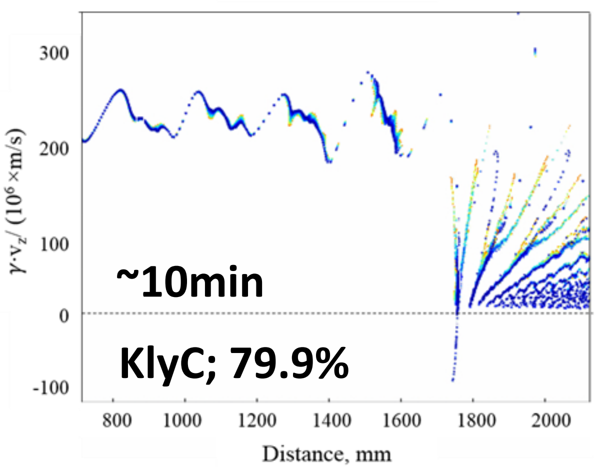
FCC CSM tube has been developed and optimised using KlyC klystron code.

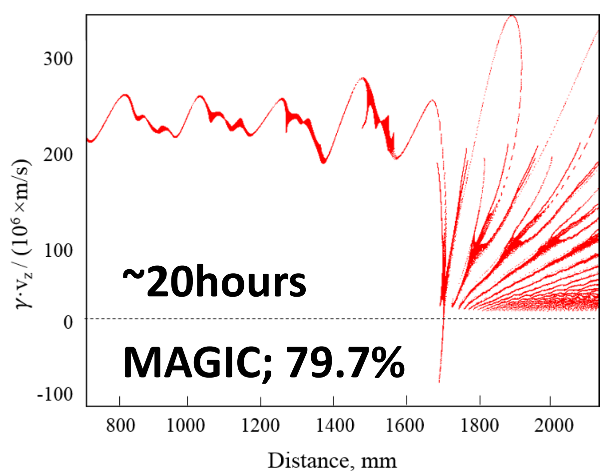


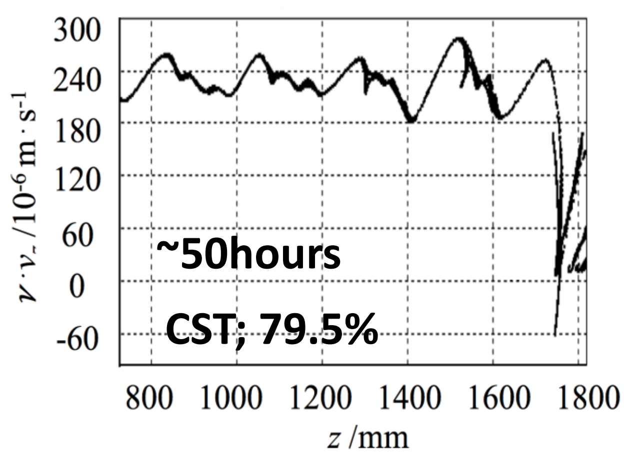
The FCC CSM KlyC based design has been intensively benchmarked against 2D PIC (MAGIC) and 3D PIC (CST) codes (Bz=4xBbr). The agreement between all 3 is within half percent in efficiency.











The new Parameters Scaling Procedure (PSP) has been recently developed at CERN. The PSP allows the instant scaling of the given klystron design to another one and to preserve the bunching processes:

Klystron 1 →

Modification of:

- Beam power
- Beam perveance
    - Voltage
    - Current
- Frequency
- Number of beams (MBK)

→

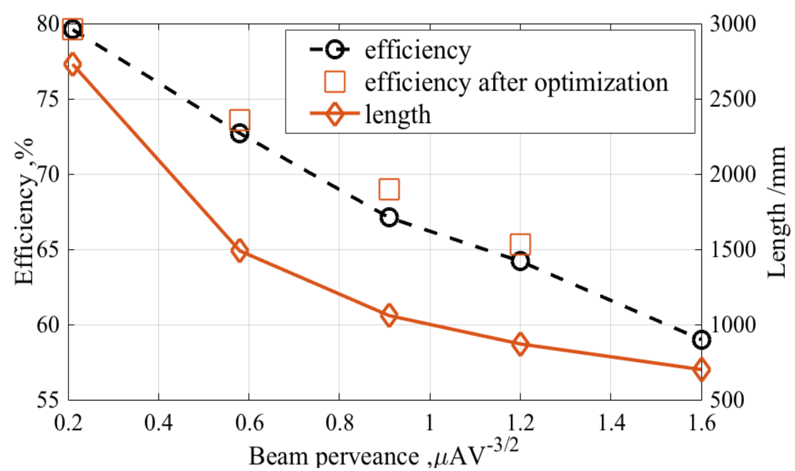
PSP acts on:

- Drift tubes length
- Drift tube aperture
- Cavities F tunings
- Cavities impedances
- Cavities beam coupling
- Loaded q-factors
- Input power

→ Klystron 2

If the perveance is not changed, the efficiency of the scaled tube will be preserved.

The example shows the direct scaling (dotted line) and post-optimisation (squares) of the 5 cavity, 2 MW COM L-band klystron.



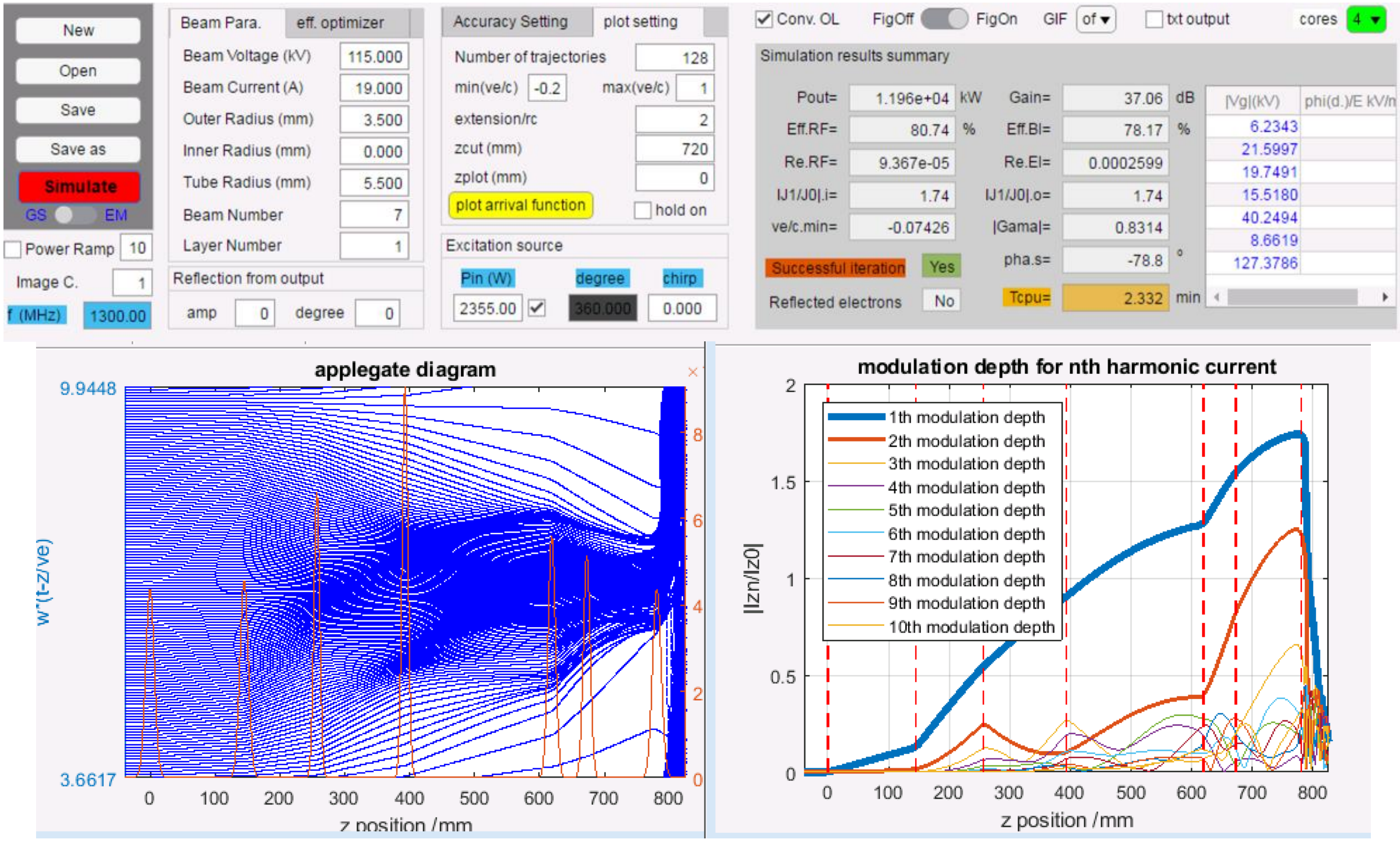
As an example the single beam FCC CSM tube was scaled to the ILC 7-beam MBK (Thales-like)

	FCC CSM	ILC CSM MBK	ILC/Thales MBK
Frequency, GHz	0.8	1.3	1.3
Total current, A	12.55	133	130
Voltage, kV	133.6	115	115
N beams	1	7	7
Efficiency,%	**80**	**76.3**	**70**
RF power, MW	1.38	11.7	10
Power gain, dB	38	47.6	47
RF Length, m	1.7	0.8	1.2

Scaling has been done using the equivalent single beam klystron. The RF cavities impedances and beam couplings were evaluated to provide values that are matched to the MBK 1.3 GHz design.

FCC -> ILC, step #1

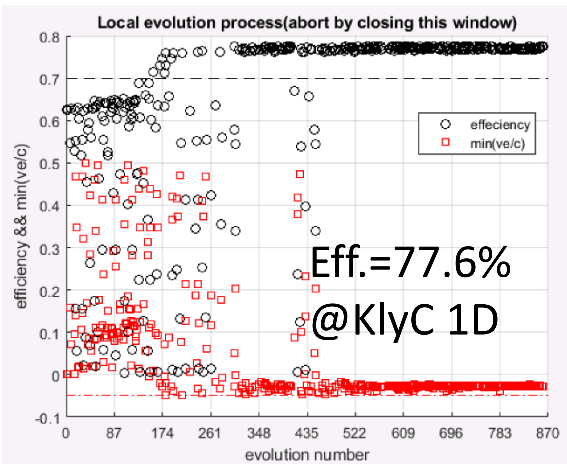
In KlyC/1D simulations, the direct PSP scaling of FCC tube to the ILC parameters predicted 78.2% efficiency.

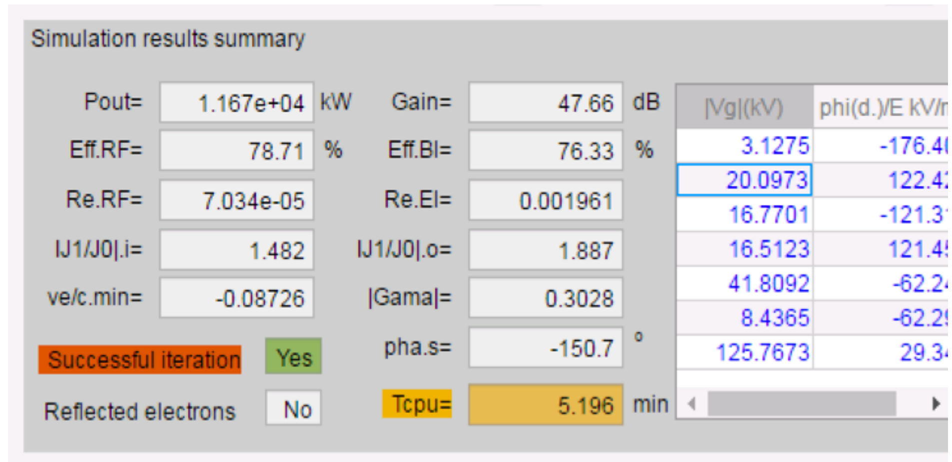


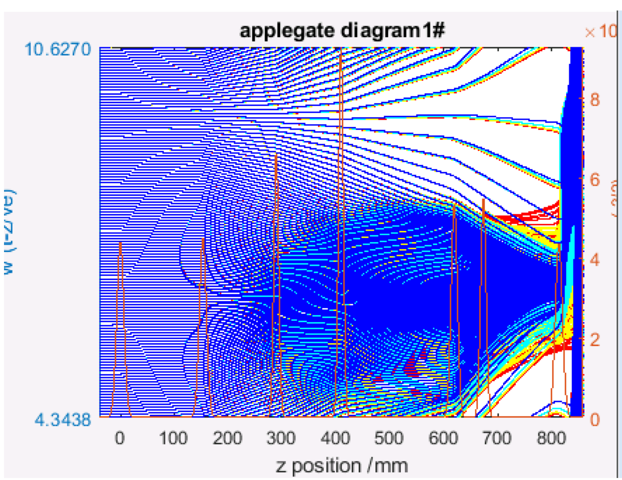
FCC -> ILC, step #2

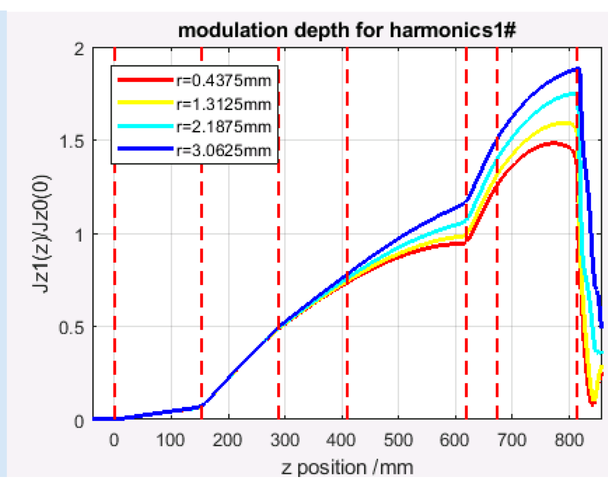
The scaled ILC CSM has low power gain. The first bunching cavity was 1) retuned to provide 47dB gain (eff. dropped to 63%) and 2) tube was re-optimised using internal KlyC optimiser (eff. Increased to 77.6%).

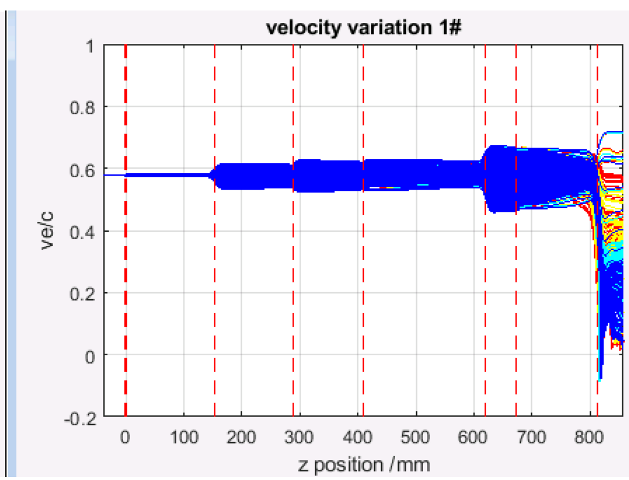
KlyC /2D simulations of this tube predicts 76.3% efficiency. Further 2D optimisation can improve the tube performance.











Summary of HE klystrons activity at CERN

- The bunching technologies for the HE klystrons have been developed, evaluated and implemented for the HE tubes design (LHC, FCC and ESS).
- The fast and accurate 1D/2D klystron code KlyC has been developed to facilitate the in-house simulations and optimizations. KlyC is a free available product.
- The Parameters Scaling Procedure (PSP) has been developed, that enables very reliable scaling of the existing tubes if some parameters need to be changed.

As an example, the HE klystron methodology developed at CERN has been applied to make a scaled design of the ILC CSM klystron with efficiency of 76.3%.