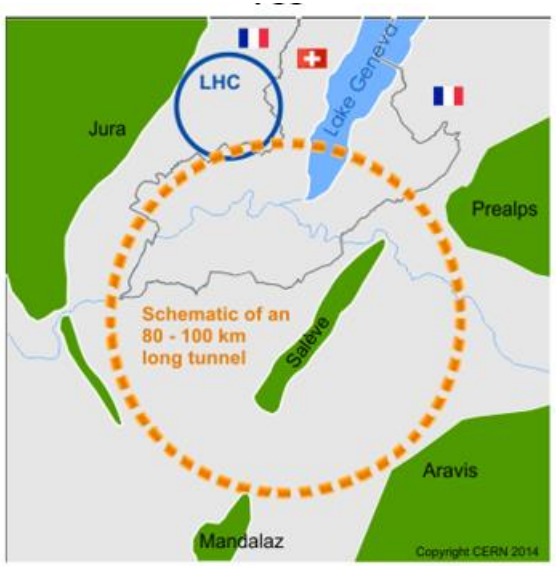
Advanced techniques for high efficiency klystron simulation

Jinchi Cai, Igor Syratchev

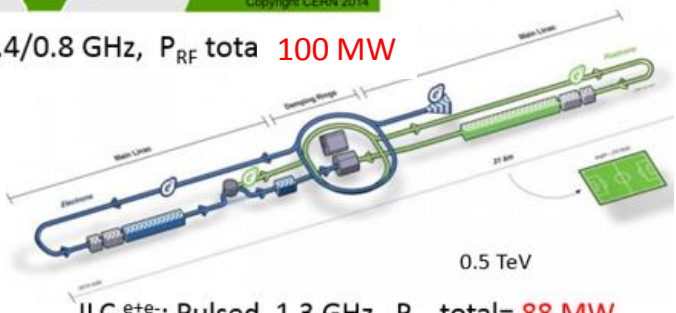
On behalf of HEIKA team

HEIKA

High efficiency! How high it could/should be!?

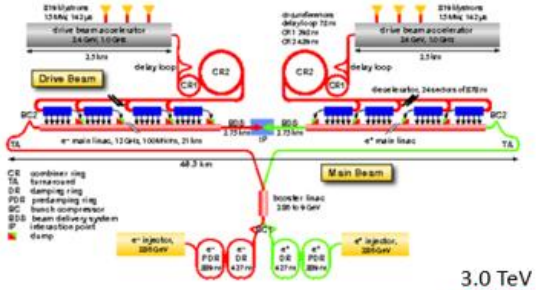


FCC ee: CW, 0.4/0.8 GHz, P_{RF} tota 100 MW



0.5 TeV

ILC e+e-: Pulsed, 1.3 GHz, P_{RF} total= 88 MW

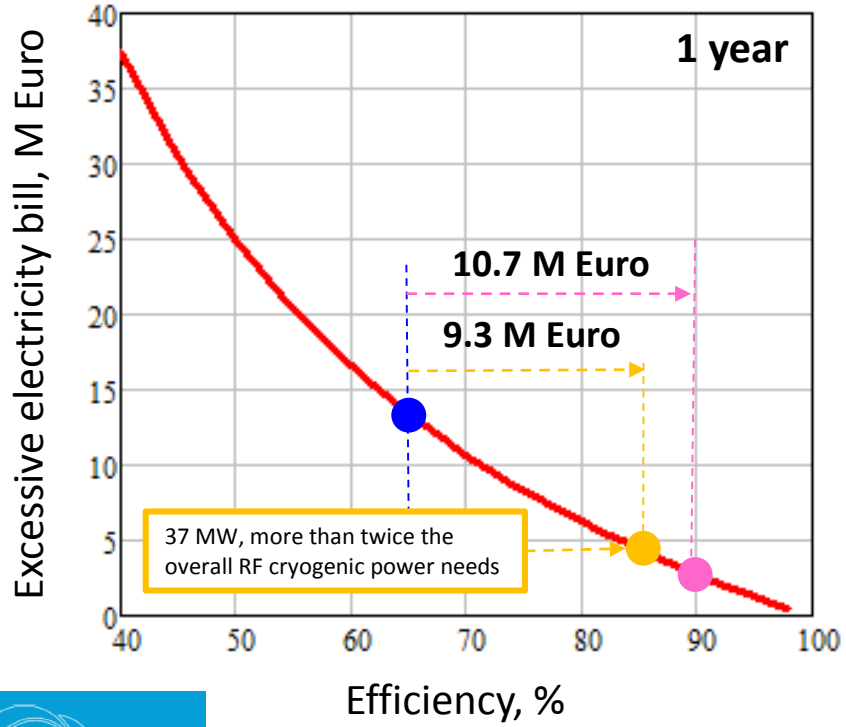


3.0 TeV

CLIC e+e-: Pulsed, 1.0 GHz, P_{RF} total= 180 MW

Efficiency impact on operation cost

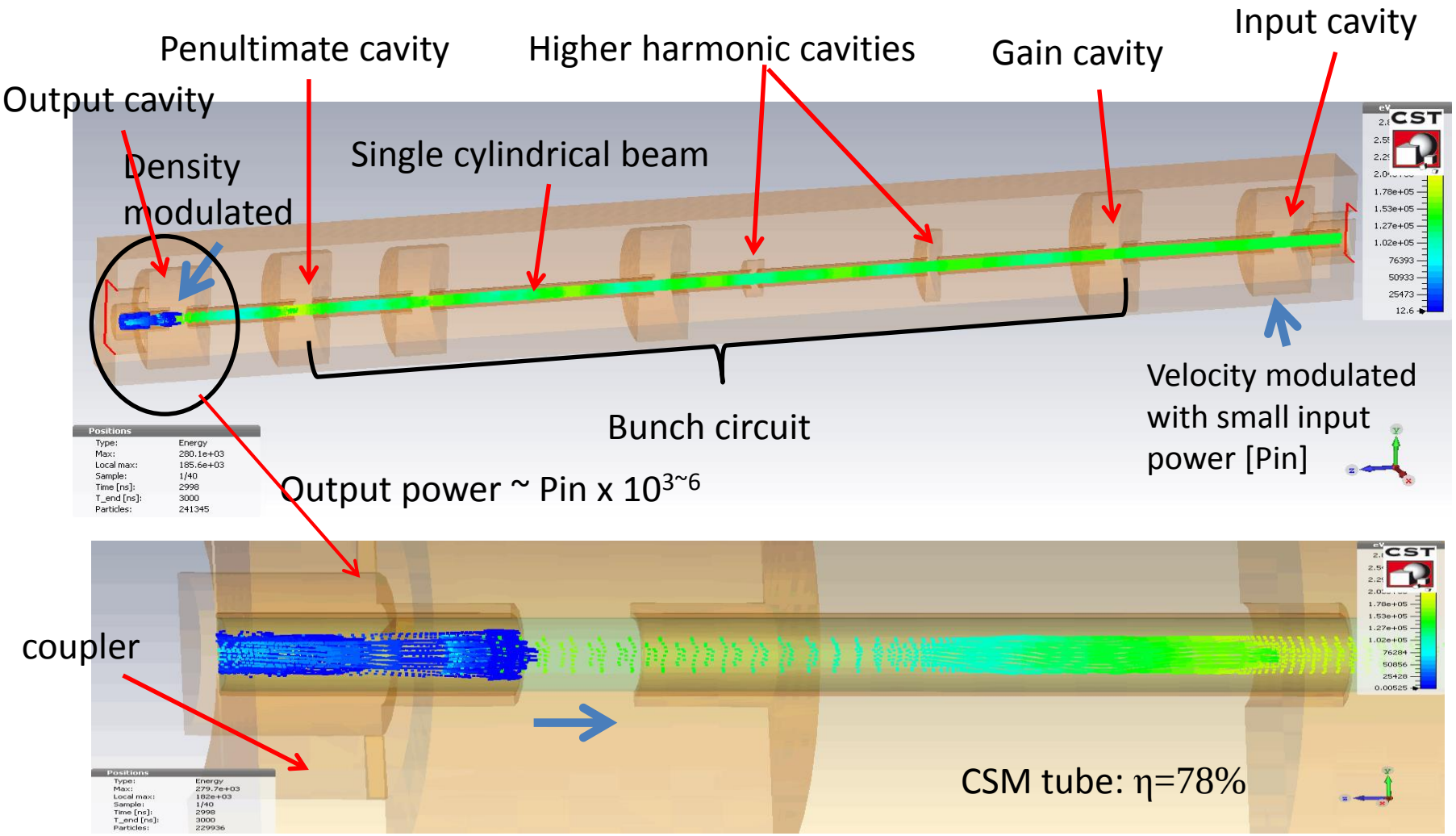
FCC e+e- at 50 Euro/MWh and 5000 hours/year:



EUROPEAN SPALLATION SOURCE

Pulsed, 0.7 GHz,
92 MW

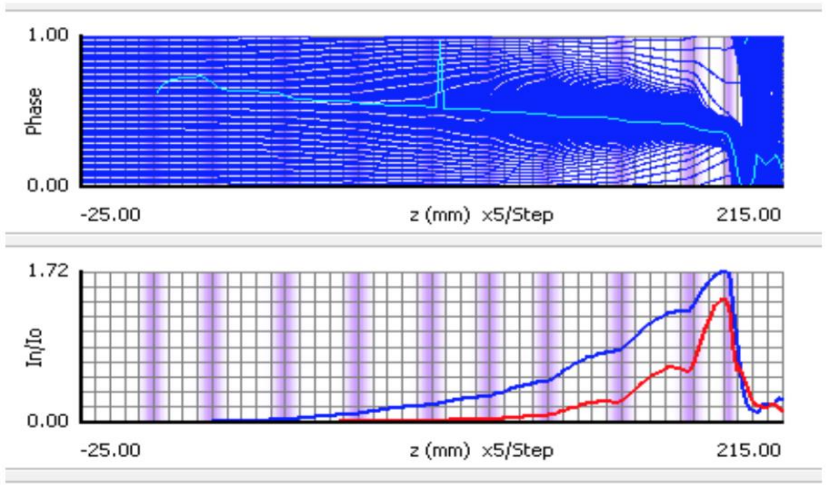
Mechanism and concepts



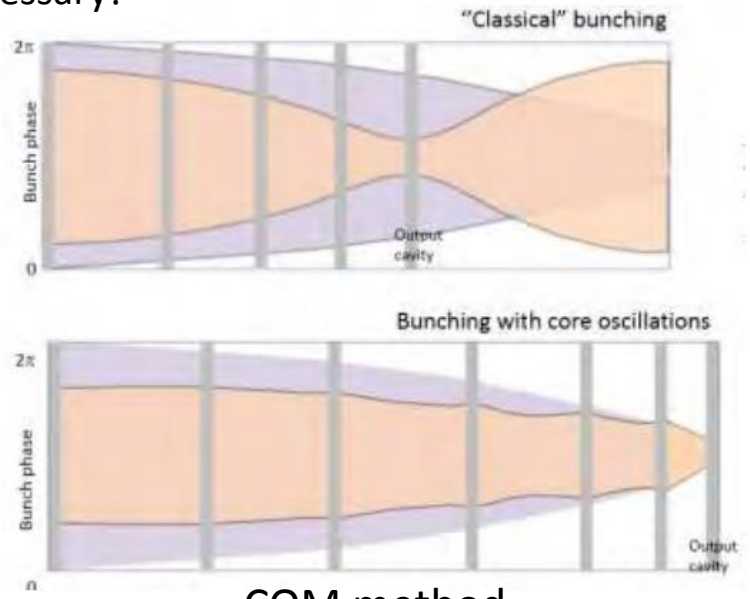
Glossary: Saturation, velocity congregation, Radial stratification

High Efficiency International Klystron Activity lead by CERN

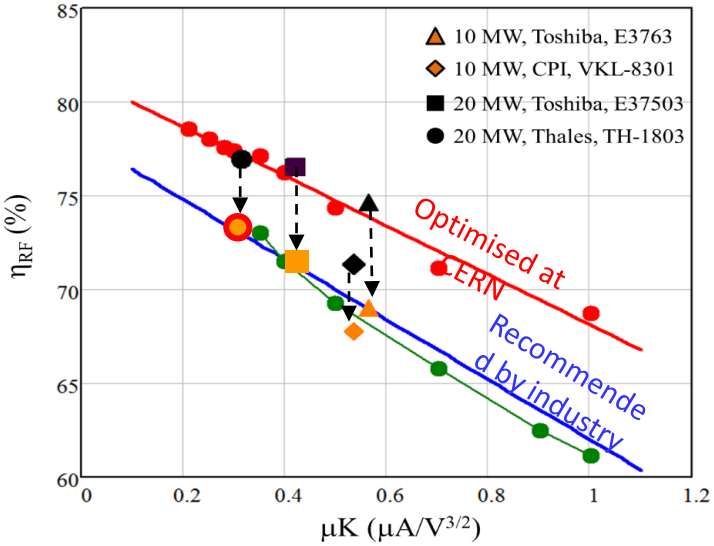
Partitioning analysis and massive optimizations are necessary!

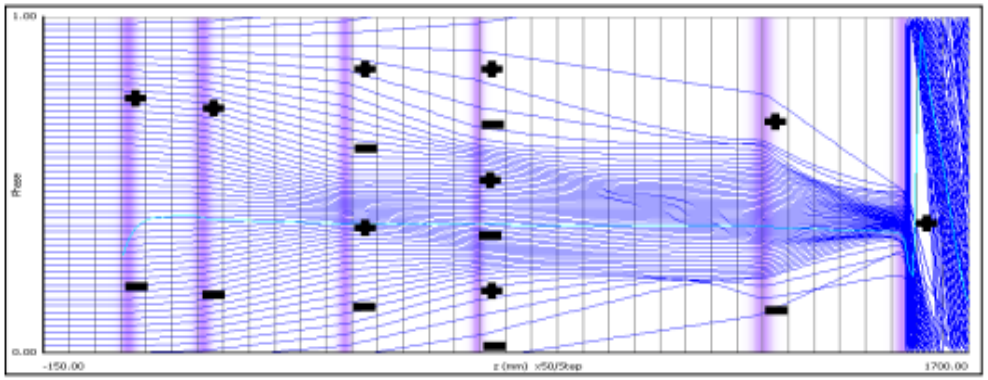


Kladistron



COM method





CSM method

Available Simulation tools

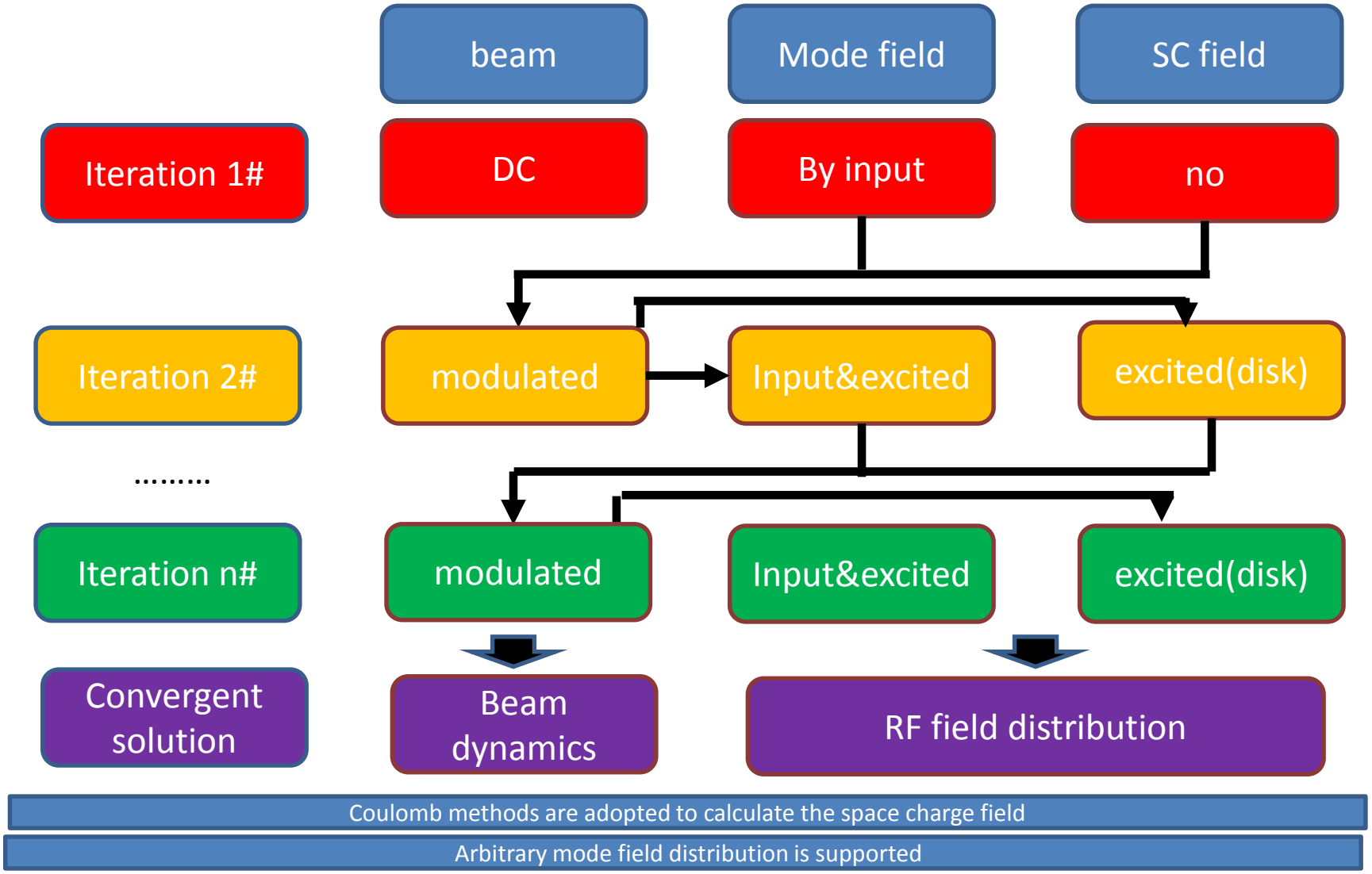
- Disk model: AJDISK,Klys4.5,Dev5,Klypwin
- Discrete model: Tesla, **KlyC**
- PIC:FCI,MAFIA,CST PIC, Magic, GDFIDL, Vorpal (+?)

Of all of them only AJDisk is a non-commercial product.

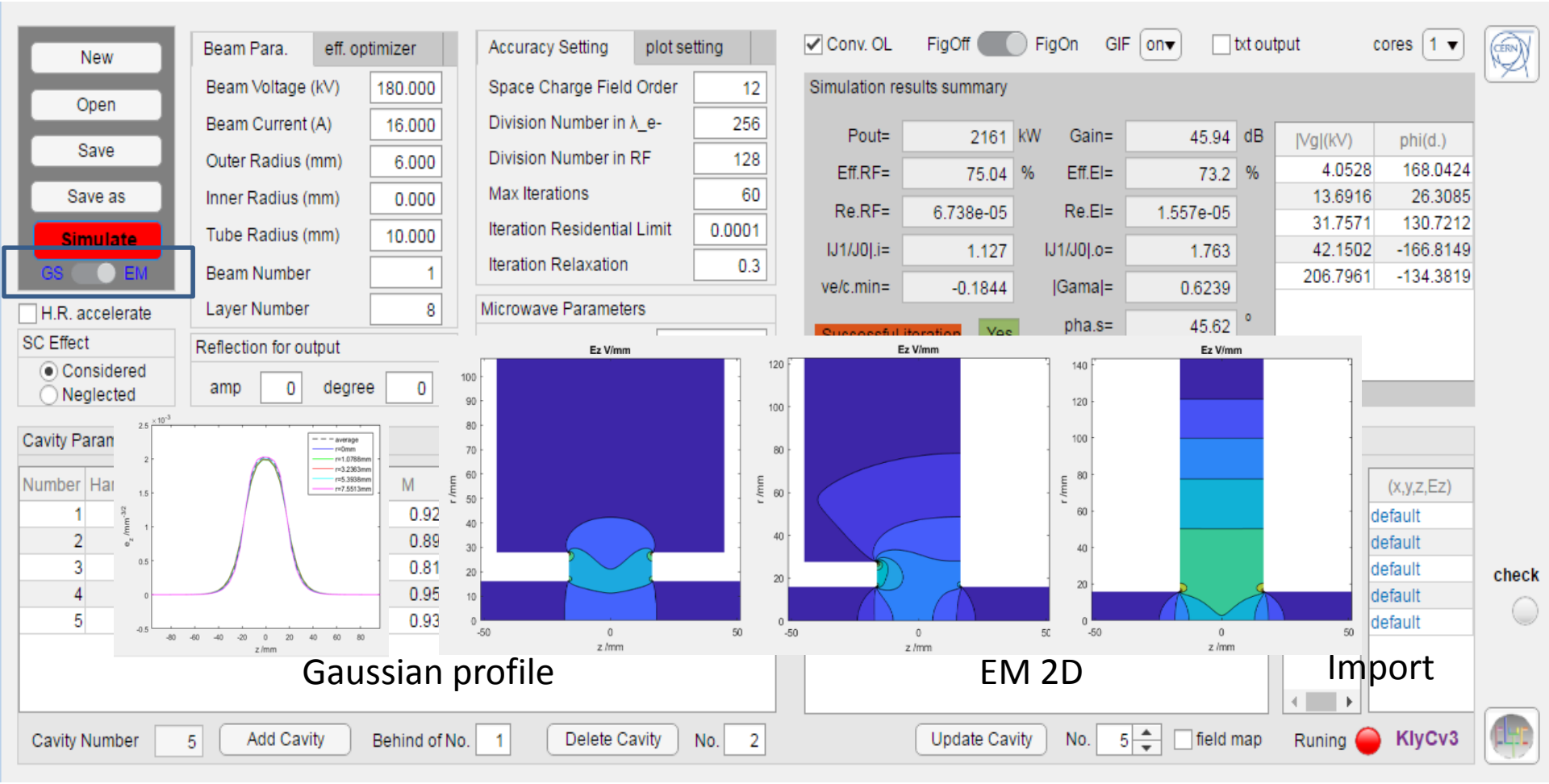
Klyc1D/2D potentials:

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, full adapted for special needs (partitioning, bunched beam generation etc.) and versatile output data interface.

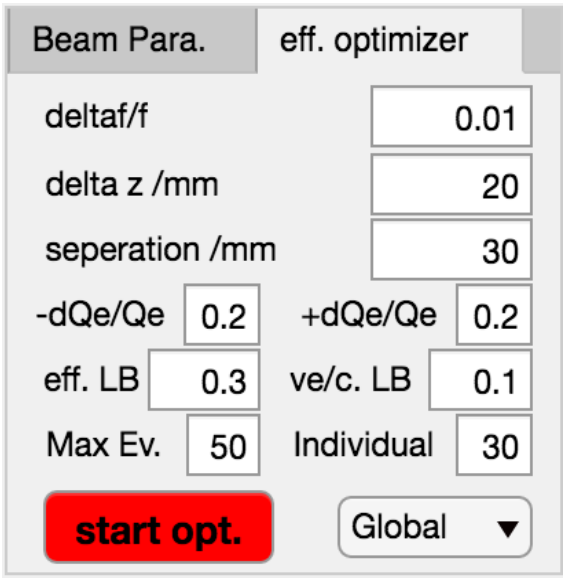
Simplified Algorithm for code “KlyC”

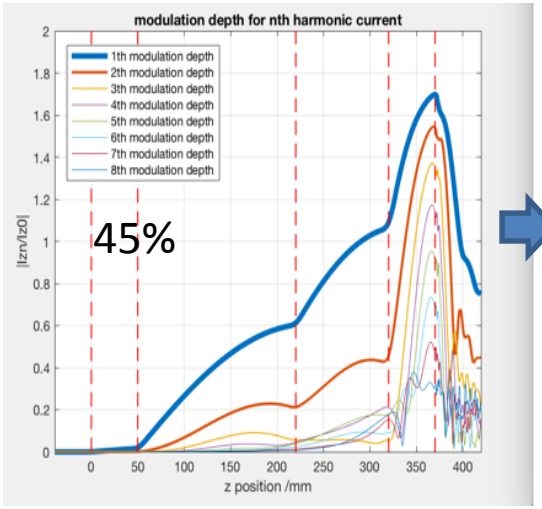


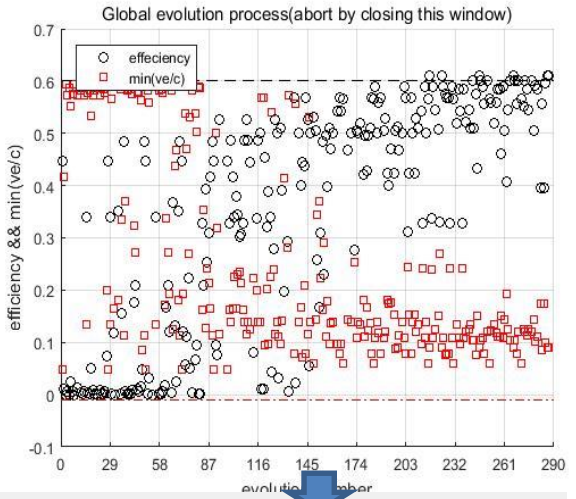
KlyC Graphical User Interface

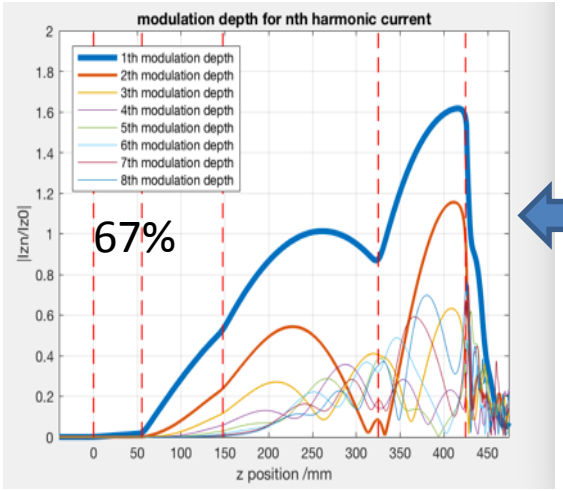


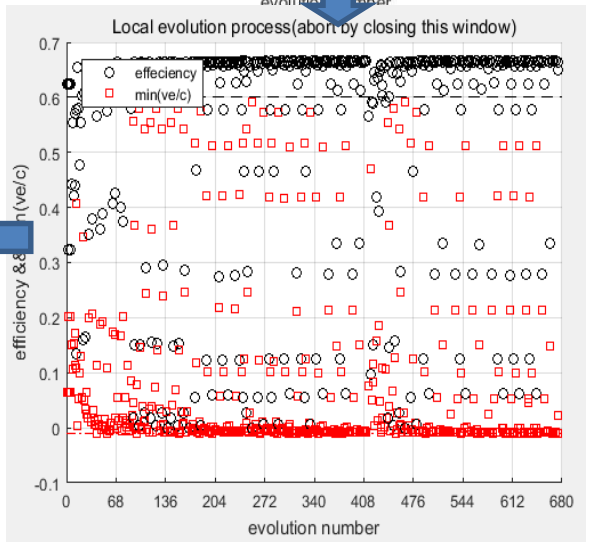
Eff. Optimizer in KlyC











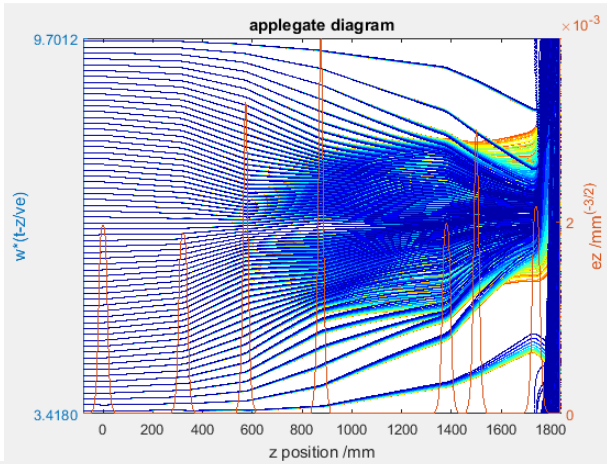
- Global: genetic algorithm
- Local: pattern search
- S band, perv.=1.9μP
- 3 days for optimization

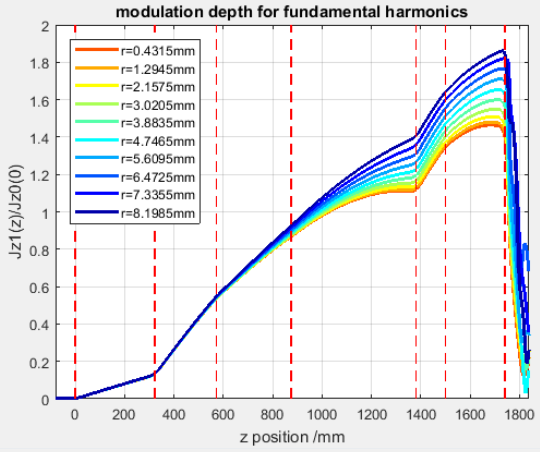
FCC Klystron design

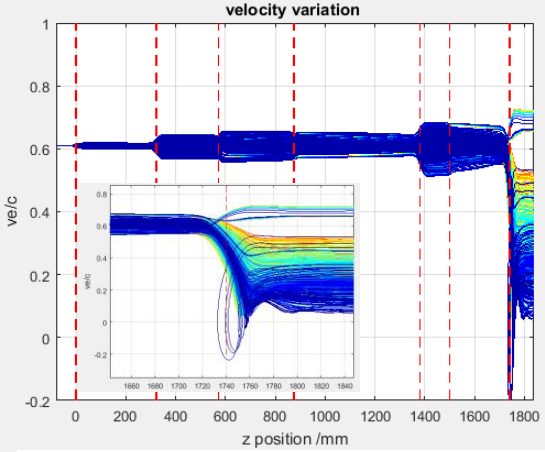
- Scaling method to get the initial CSM design
- Optimized in KlyC1D(~2min per case)
- Polished in KlyC2D(~20min per case)
- Performance summary and Sensitivity analysis in KlyC2D
- Verified by Magic 2D(12h per case) and CST 3D(50h per case)

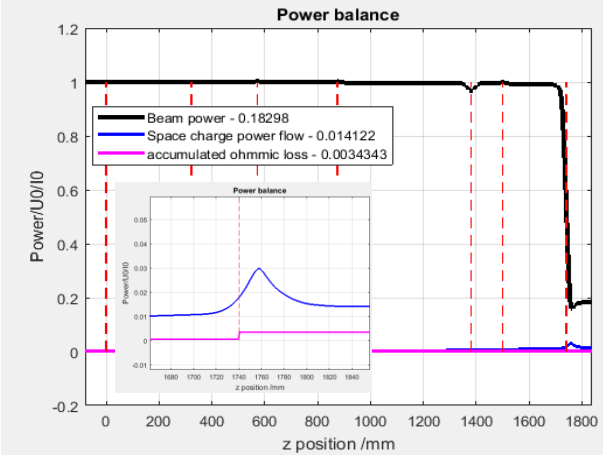
FCC e^+e^-:

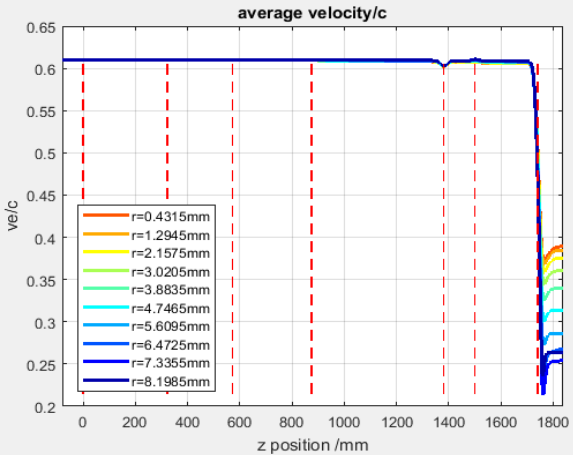
0.8GHz,133.9kV×12.5A×**80%**>1.3MW



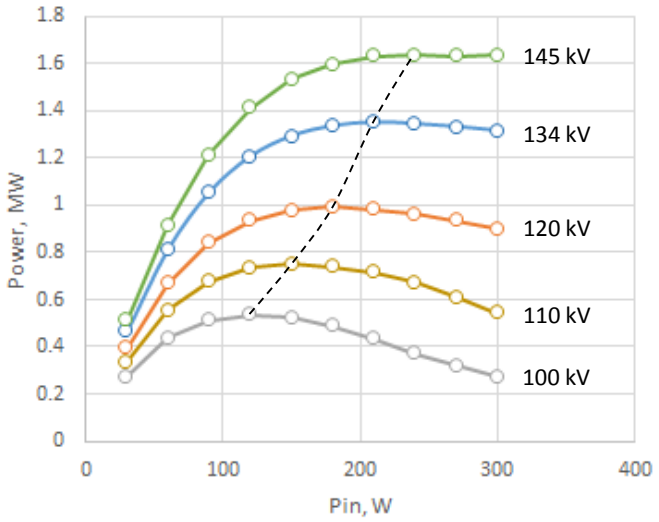


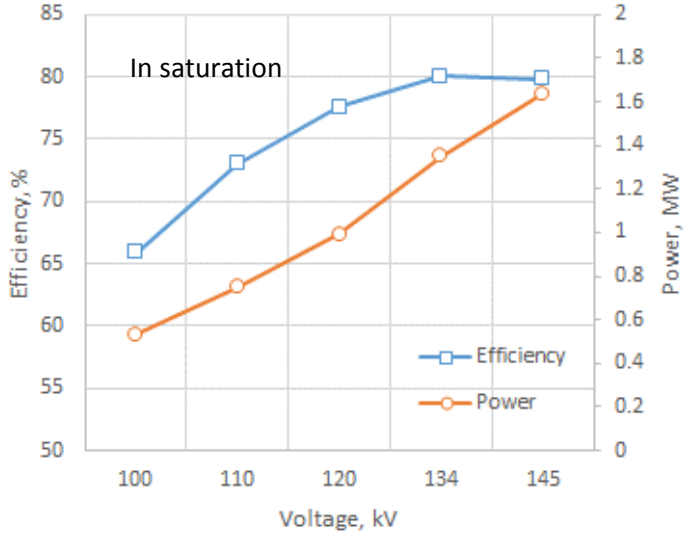


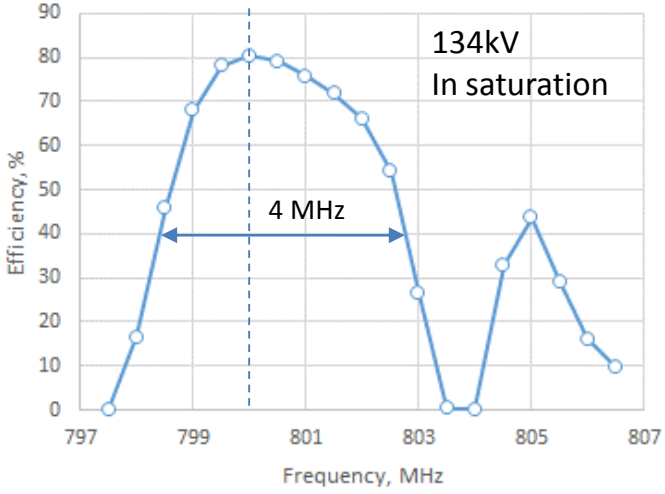


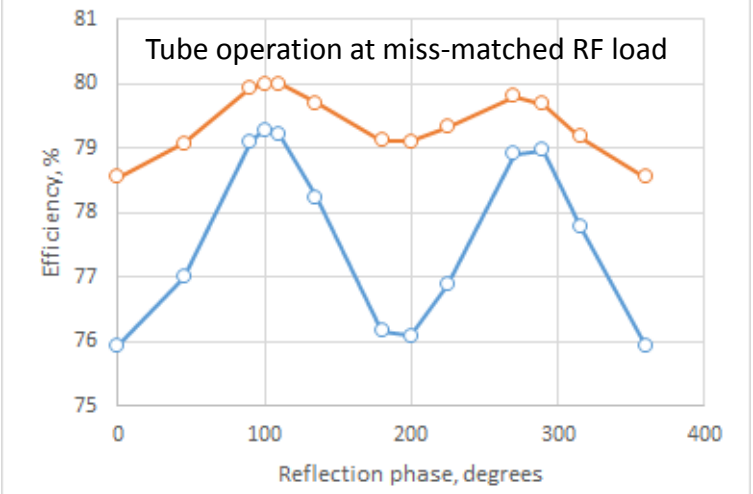


Klystron's Power gain curves and bandwidth (KlyC).

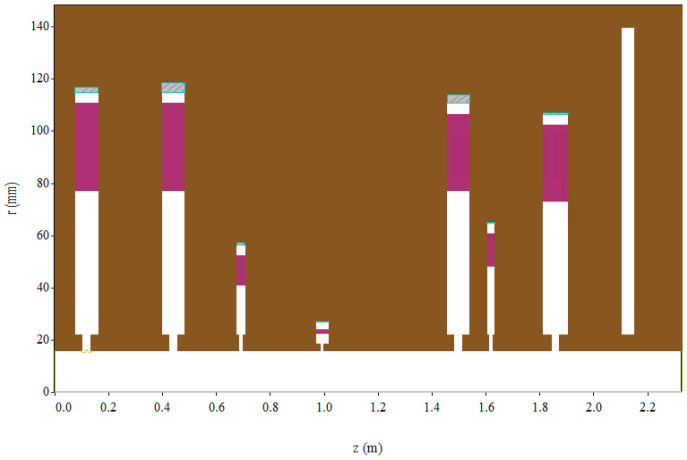


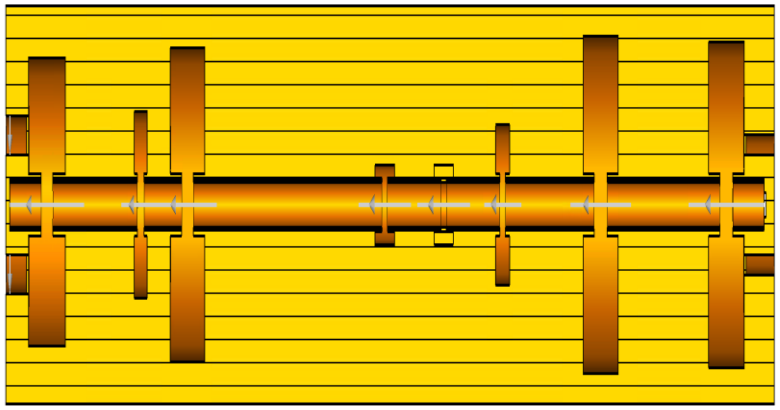






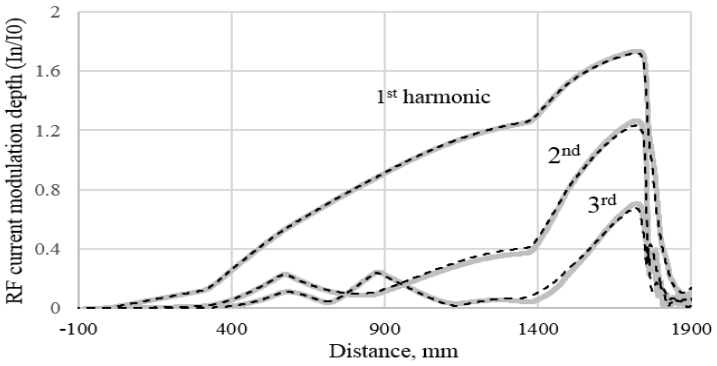
Benchmark with PIC code

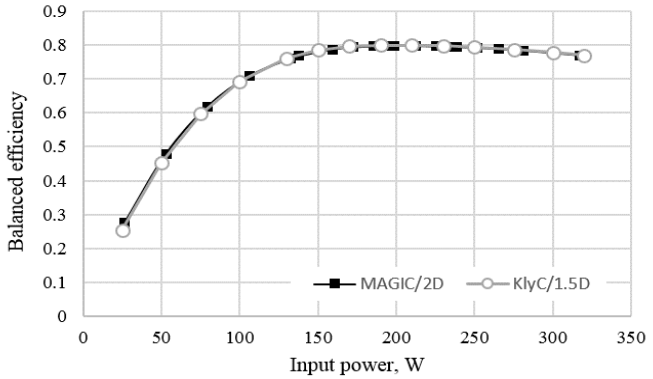




Efficiency=**80%** @Magic 2D and **79%** @CST 3D

Time cost=12 h @Magic 2D and 50h @CST 3D





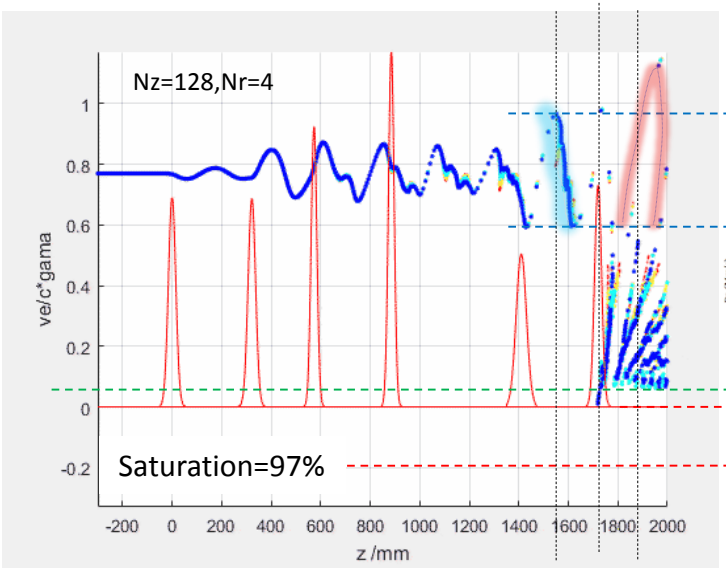
FCC#6. KlyC2D vs MAGIC

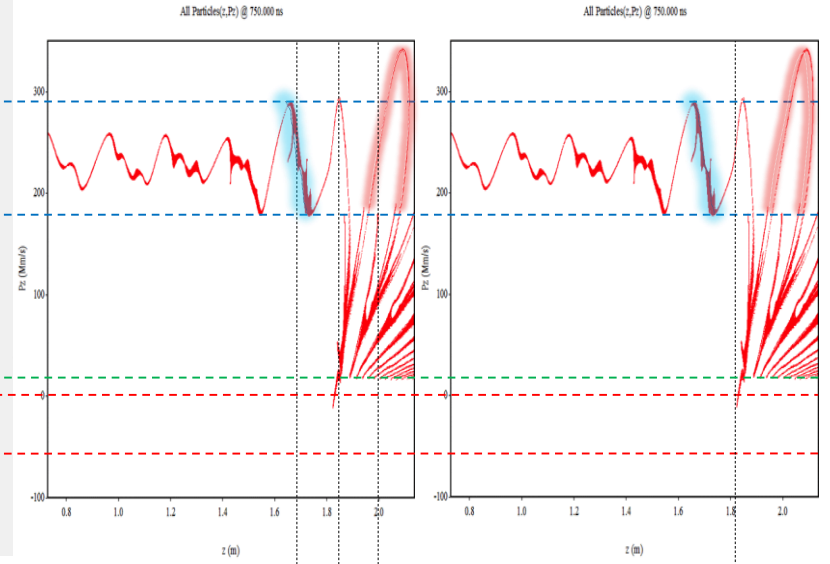
Beam settings :

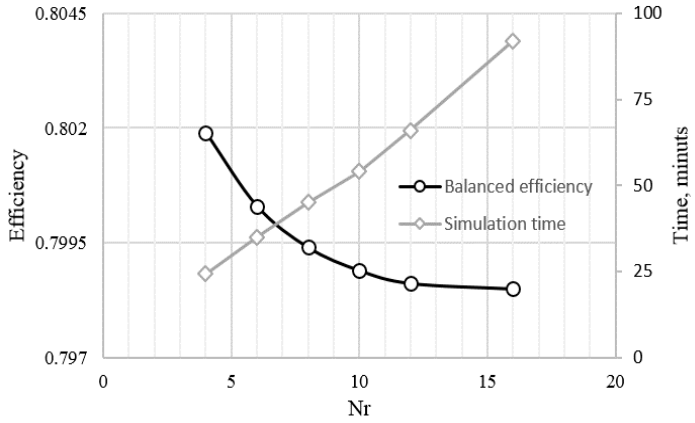
Nz=256,Nr=4, η=79.9%,Tcpu= 20 min

MAGIC (0.07T) **2D**, 79.4% MAGIC (20T) **2D**, 79.6%

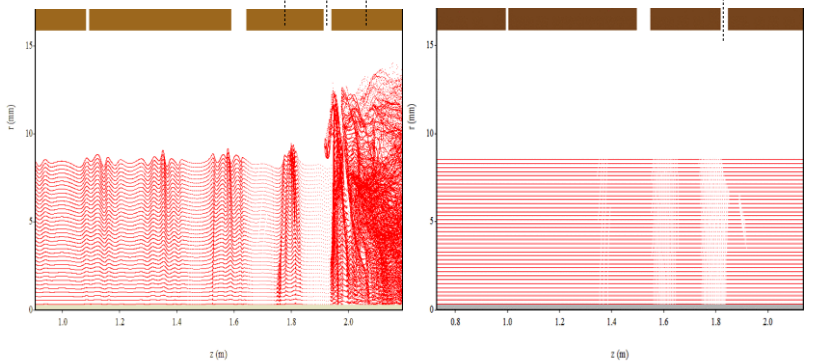
Tcpu = 4000 min (~1ooo ns)







Convergent analysis

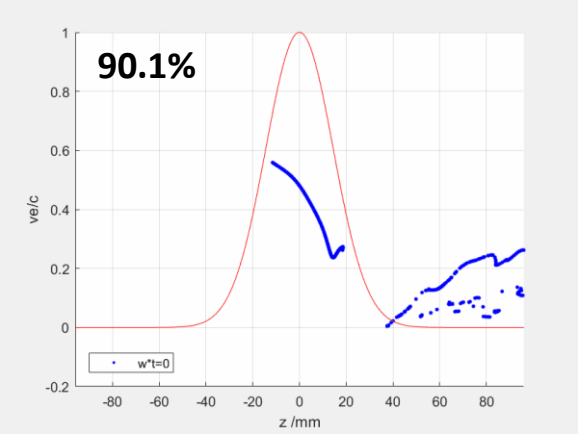


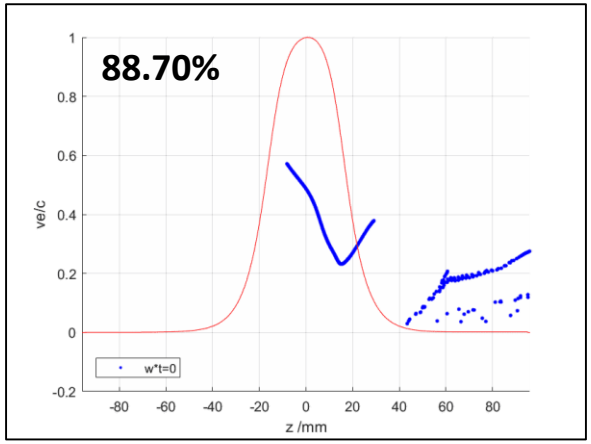
The radial bunch 'expansion' in output cavity (MAGIC2D) practically does not affect efficiency. This validates KlyC2D as an attractive (and fast) tool.

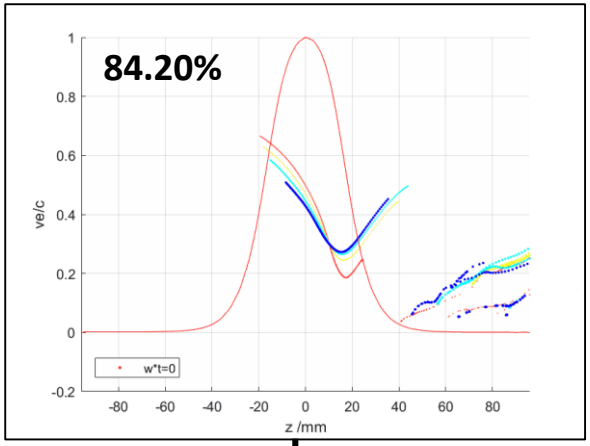
Power conversion efficiency. Limiting factors.

Fully saturated bunch

Optimised congregation → **Linear** congregation → **Stratified** bunch with linear congregation

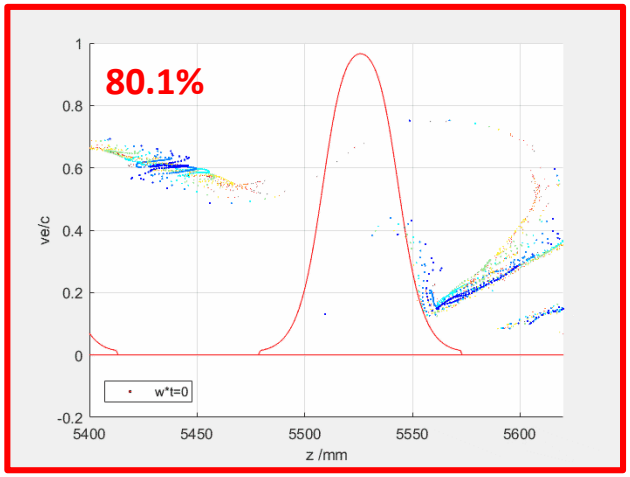




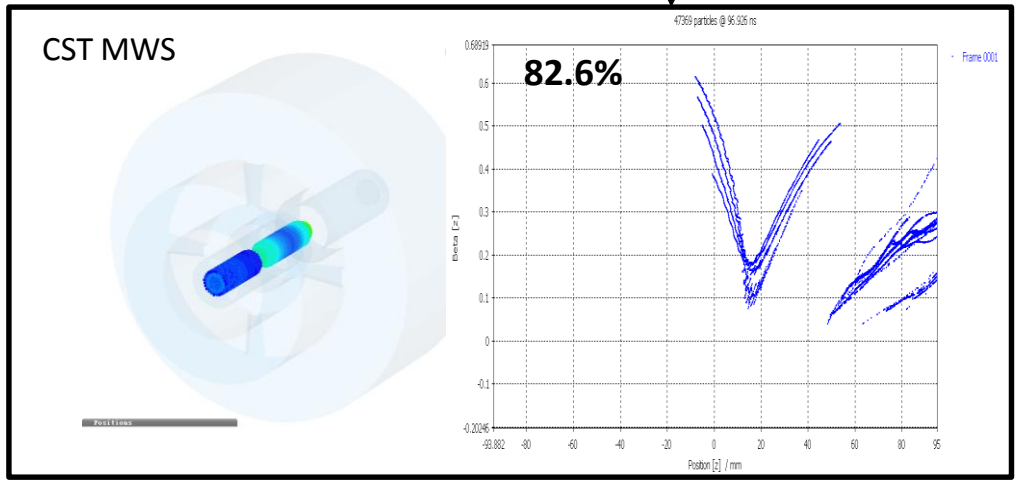


Sabre effect and Ohmic → FCC CSM tube

Benchmark with CST for the same bunch quality

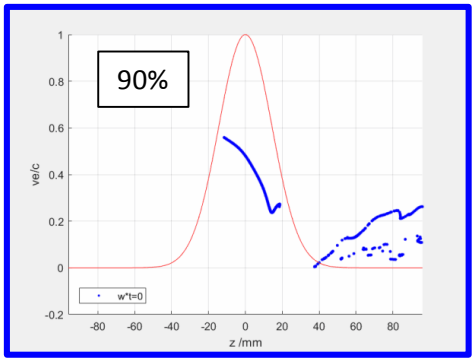


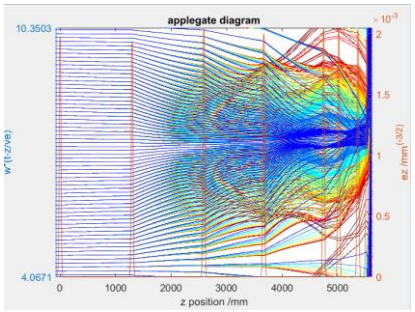
CST MWS

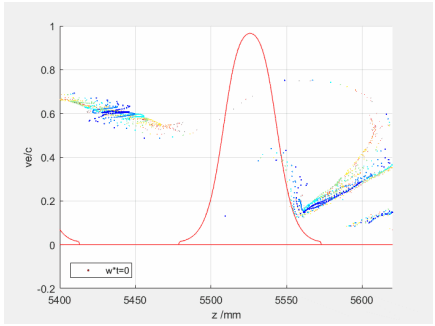


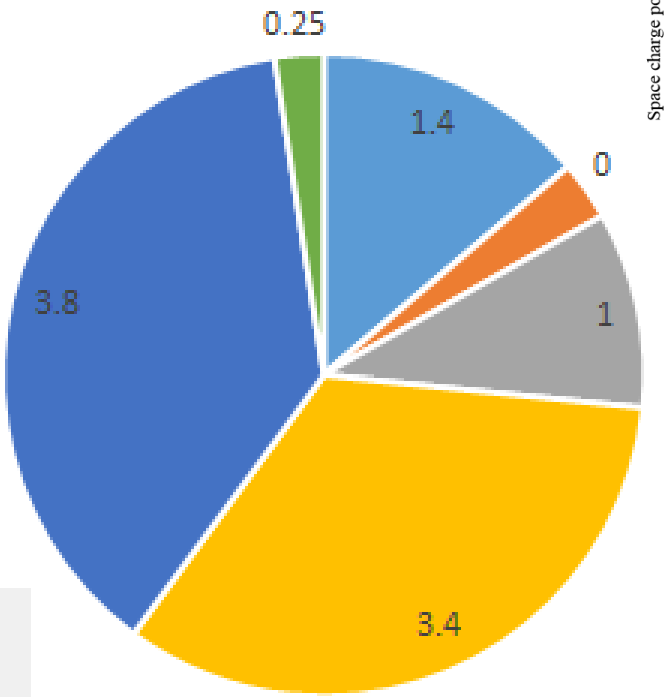
Power conversion efficiency. Limiting factors. Summary.

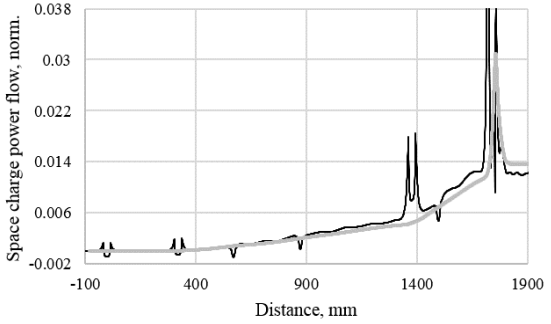
In a low perveance tube, the accumulated effect of all the limiting factors that are inherent to the bunching and deceleration processes may results in 10% efficiency reduction (from 90% to 80%).



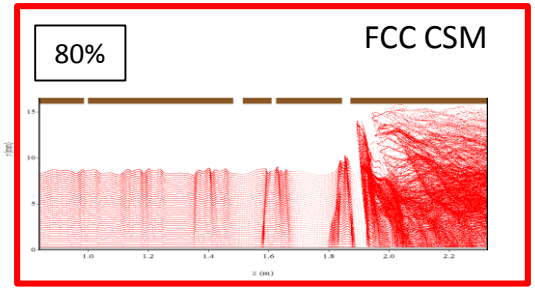




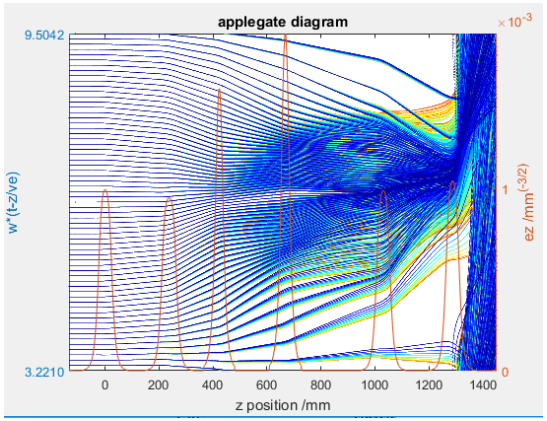


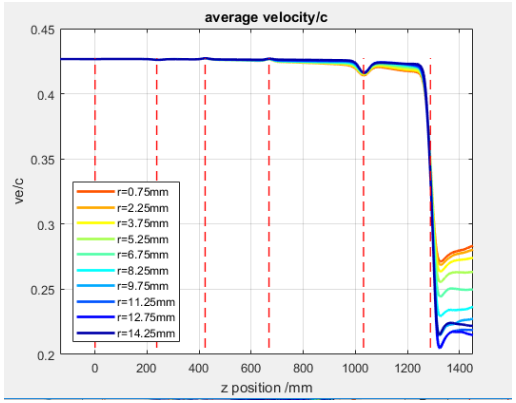


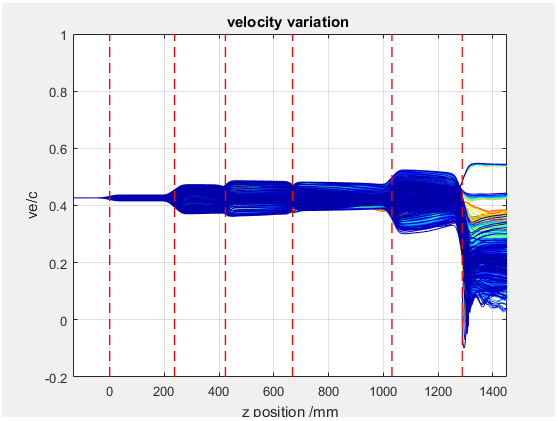
- sabre effect
- Ohmic Losses
- Bunch saturation
- Bunch congregation
- Bunch stratification
- Magnetic field

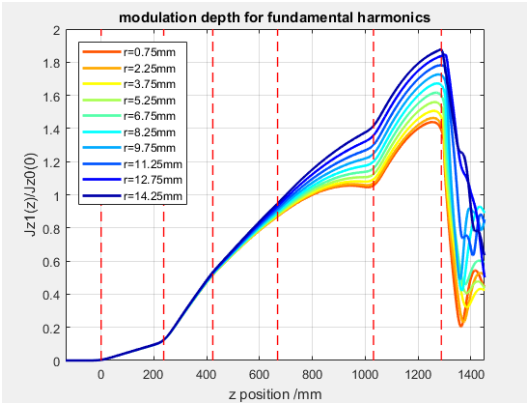


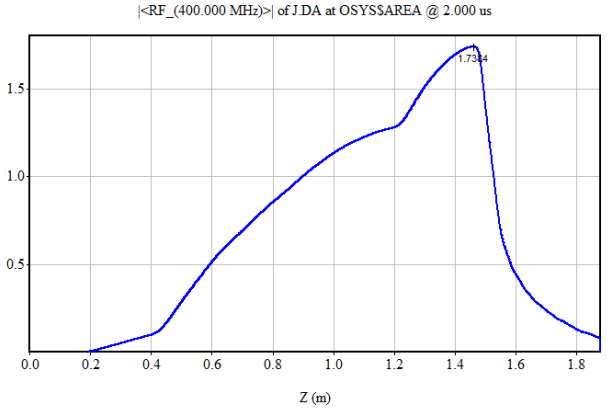
FCC h^+h^- /LHC: 0.4GHz,54kV×9A×**70%**~0.35MW (Pin=80W)

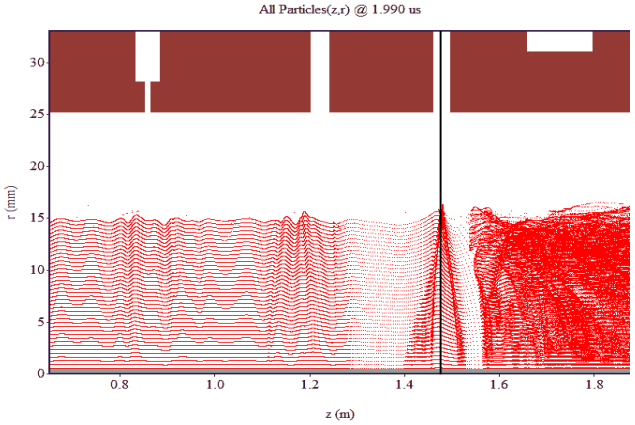












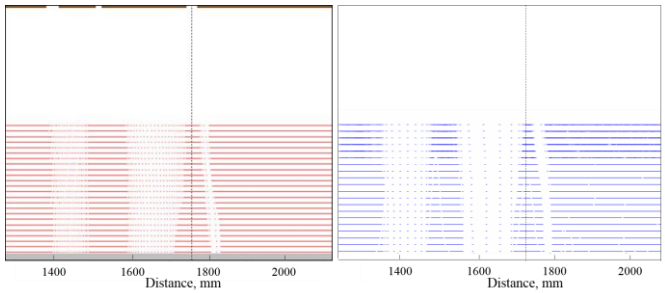
Magic Efficiency = 69.46%

KlyC Efficiency = 70.06%

Benchmark work is done by Victoria Hill

Thanks for your attention!

MAGIC PIC

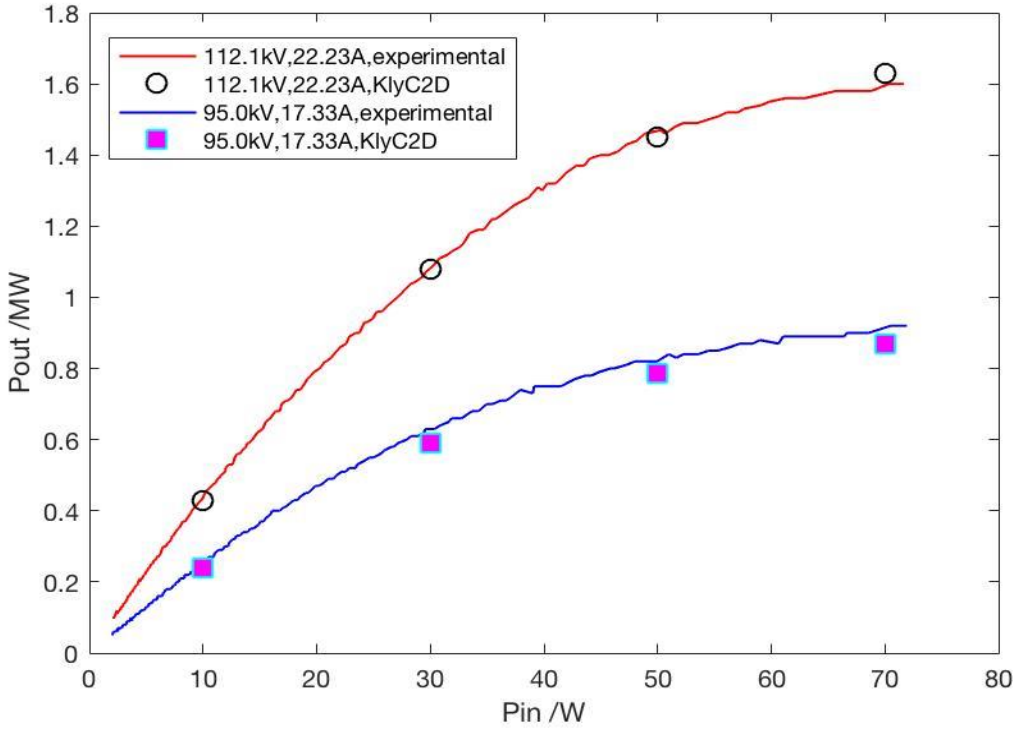


ACKNOWLEDGMENT

Authors would like to thank Z.L. Liu for his help in developing the KlyC GUI, D. Constable for providing MAGIC simulations of FCC tube

Scan QR code for More benchmark work done

Thales tube TH2180



A. Leggieri made comparison between TH2180 experimental data and KlyC simulations