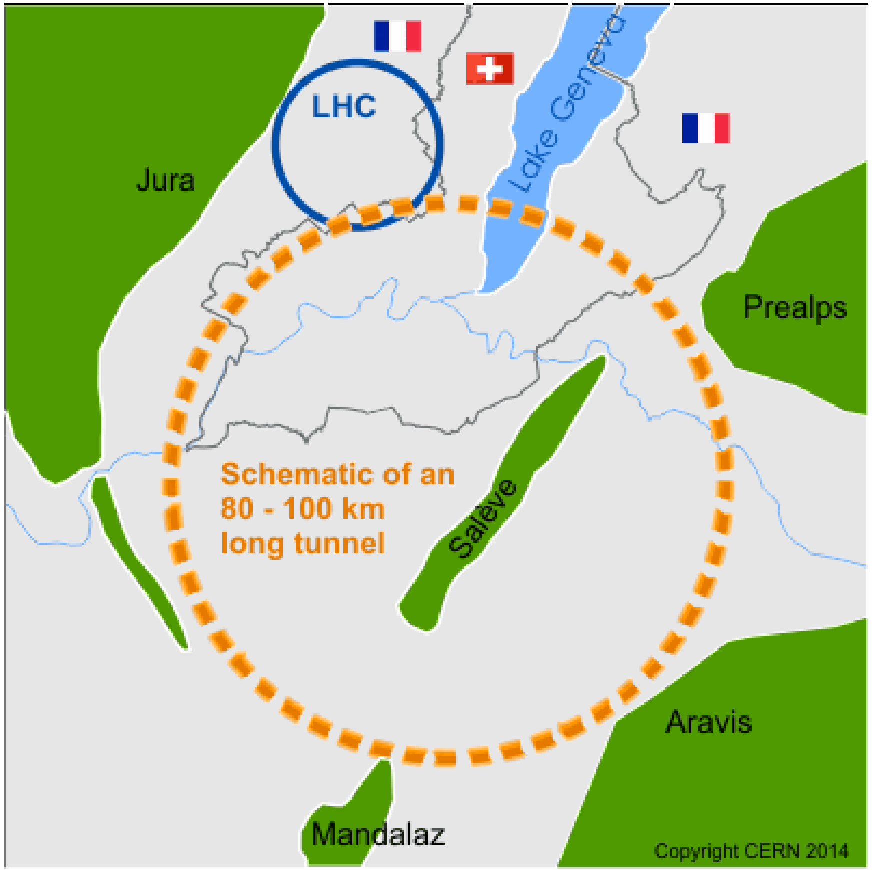
Towards high power klystrons with RF power conversion efficiency in the order of 90%.

Syratchev(CERN) on behalf of
High Efficiency International Klystron Activity
HEIKA

Future large scale accelerators

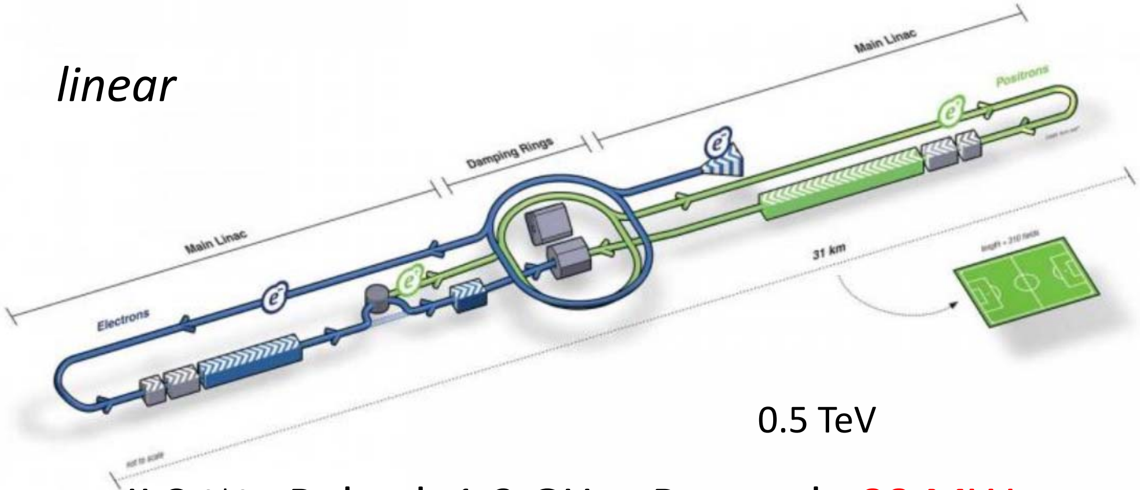
circular

FCC



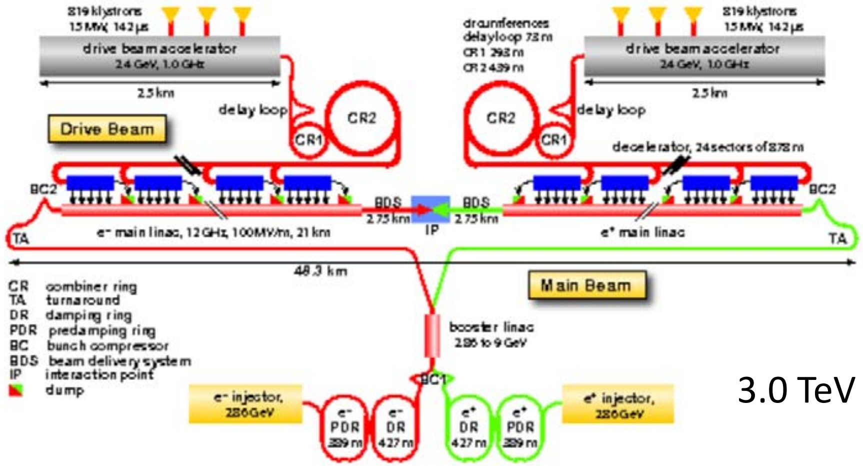
FCC ^{ee}: CW, 0.8 GHz, P_{RF} total= 110 MW

linear



0.5 TeV

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



3.0 TeV

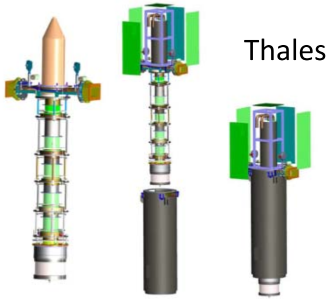
CLIC $^{e+e-}$: Pulsed, 1.0 GHz, P_{RF} total= 180 MW

Motivation for HEIKA

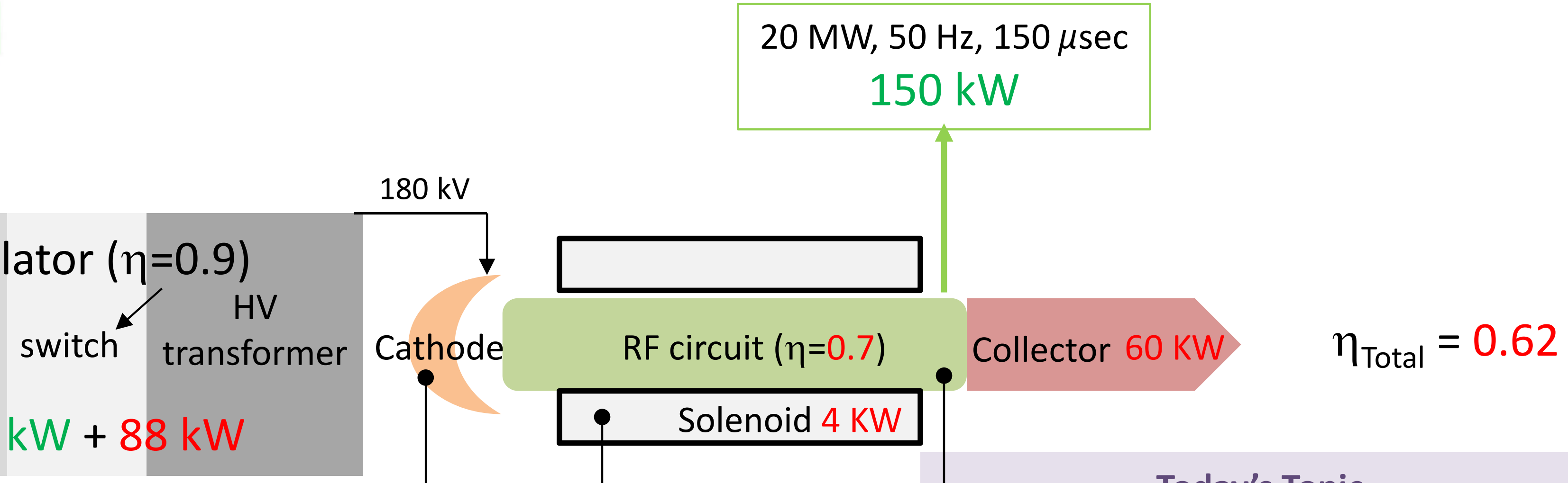
- The increase in efficiency of RF power generation for the future large accelerators such as CLIC, ILC, ESS, FCC and others is considered a high priority issue.
- Only a few klystrons available on the market are capable of operating with 65% efficiency or above. Over decades of high power klystron development, approaching the highest peak/average RF power was more important for the scientific community and thus was targeted by the klystron developers rather than providing high efficiency.
- The deeper understanding of the klystron physics, new ideas and massive application of the modern computation resources are the key ingredients to deign the klystron with <u>RF power production efficiency at a level of 90% and above.</u>

The coordinated efforts of the experts in the Labs and Universities with a strong involvement of industrial partners worldwide is the most efficient way to reach the target … thus HEIKA.

CLIC Multi-beam (6/10 beams) pulsed klystron power balance diagram.



Thales TH1803



Can we do better?

Lower (<60kV) voltage:
- 40 mini-cathodes
- No oil tank (cost)
- Shorter tube (cost)
- Faster switching (efficiency/cost)

Permanent Magnets:
- No power consumption
- Potential cost reduction

Vs. SC solenoid:
- More expensive solution

Today's Topic

New klystron RF circuit (η=0.9)
(+) Reduced Collector dissipation (16 kW)

Gated mini-cathode:
- No switches (cost)
- Modulator efficiency ~1.0

(+) Improved stability

η_{Total} = 0.9

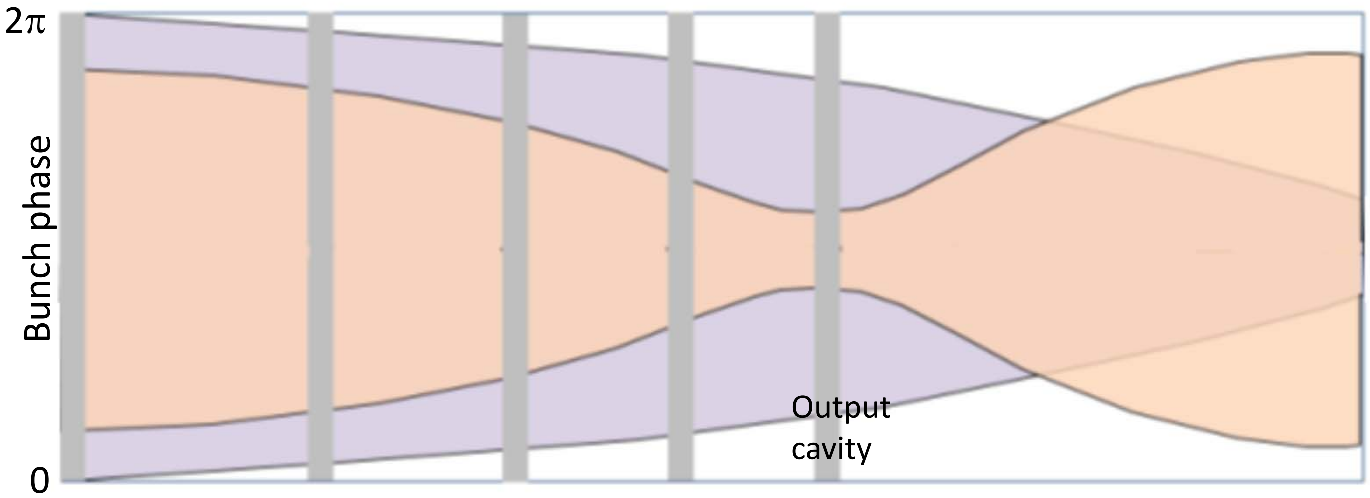
CLIC requires about 800 klystrons. Successful implementation of all the actions above could save 60MW and reduce the power plant cost by ~15%.

The new bunching technology shows a potential to boost klystron efficiency to the 90% level.

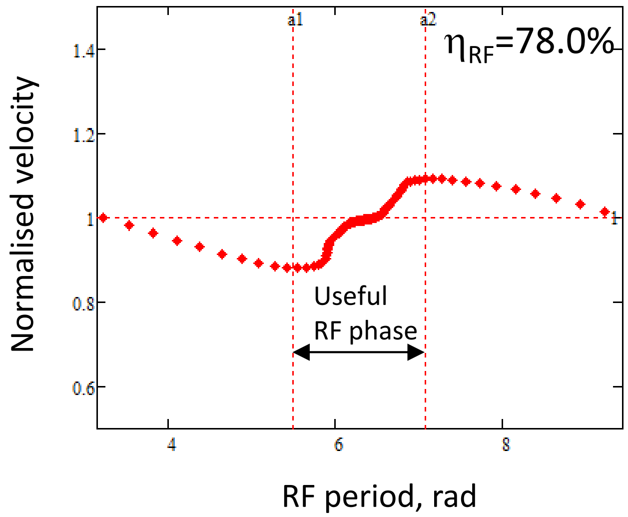
Link: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7194781

CLIC MBK preliminary optimisation

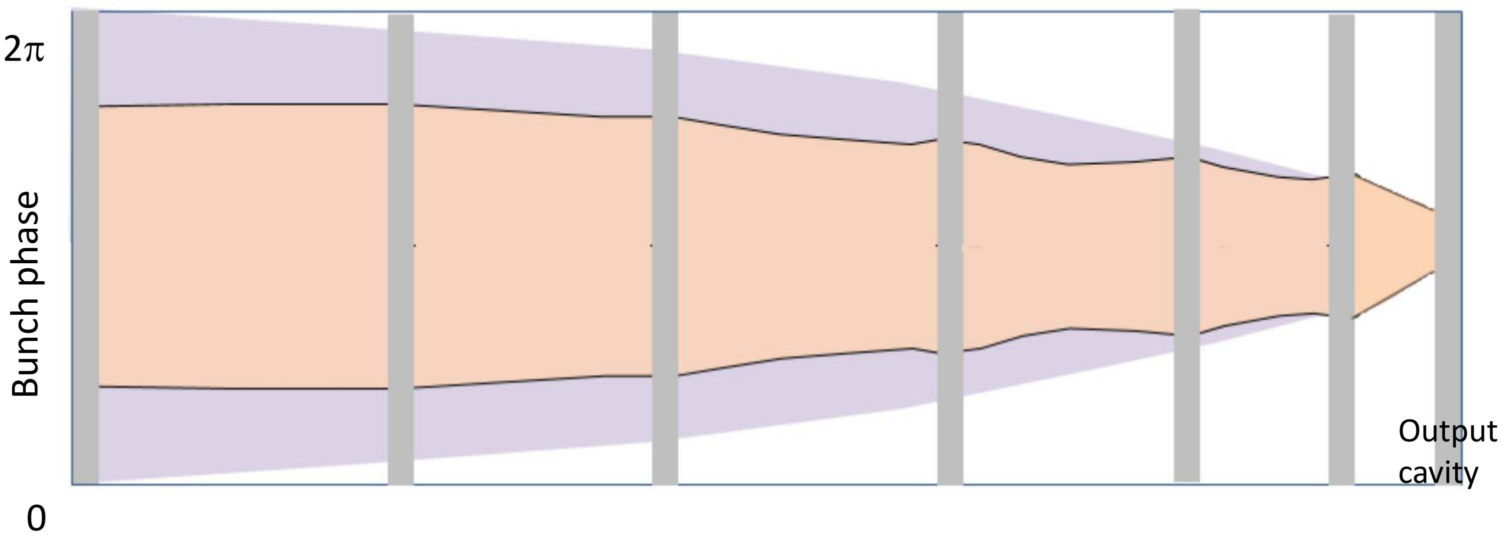
"Classical" bunching

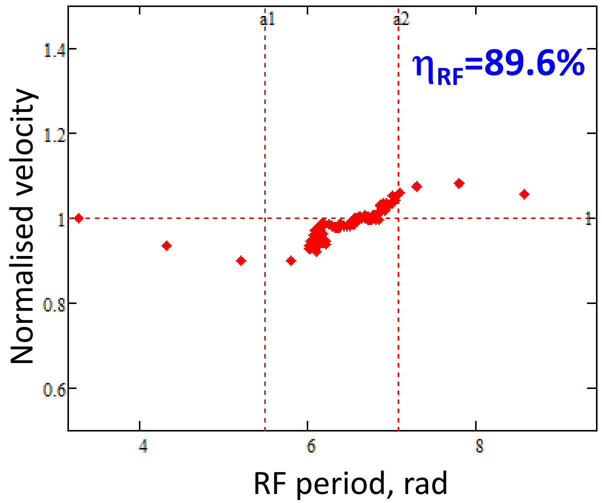


Electrons velocities distributions prior entering the output cavity



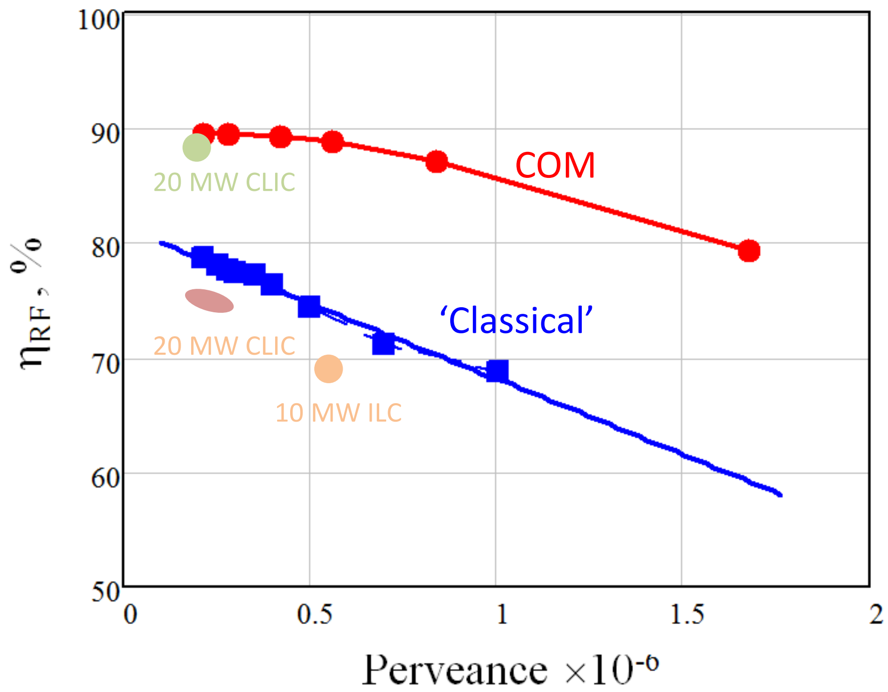
New bunching with core oscillations (COM)

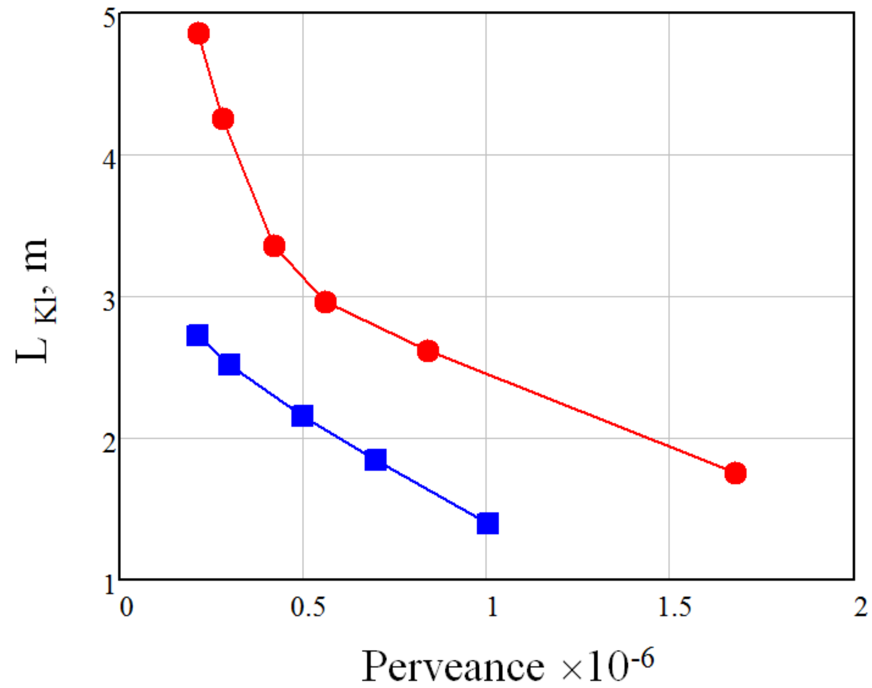


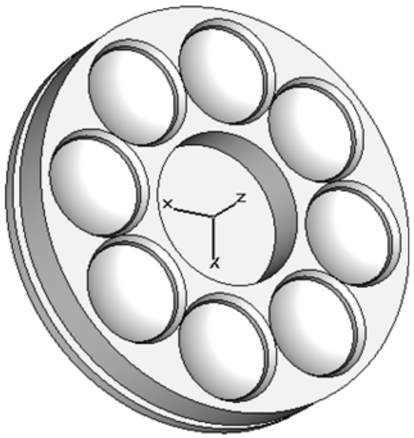


I. Syratchev, October 2016, Energy for Sustainable science, Hamburg.

Comparison of the two bunching methods (CLIC MBK).



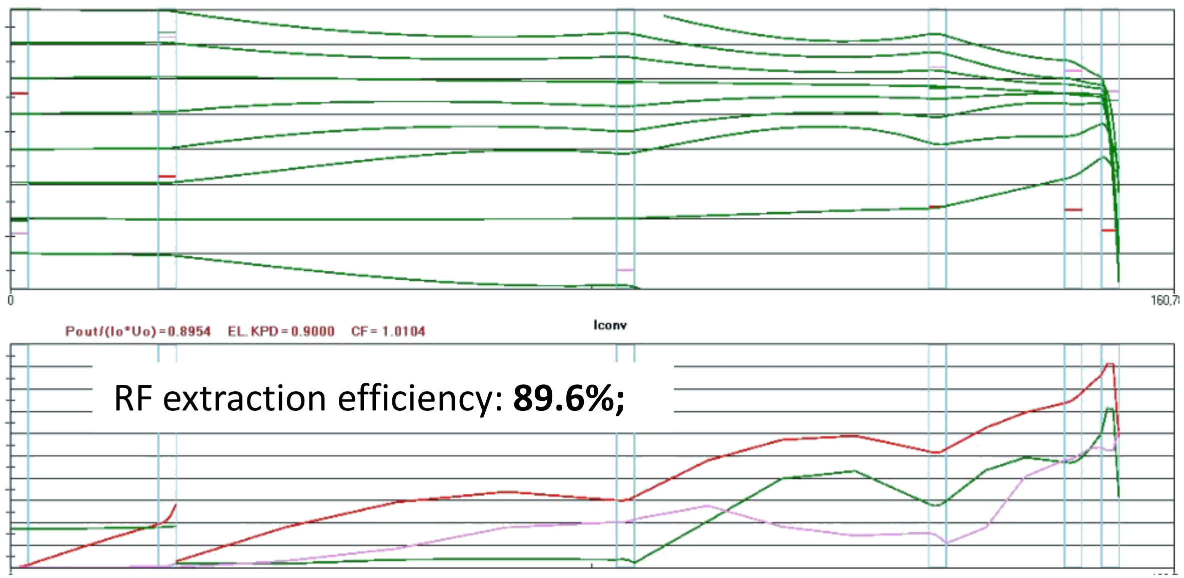




N beams = 8

V = 180 kV

I total = 128 A

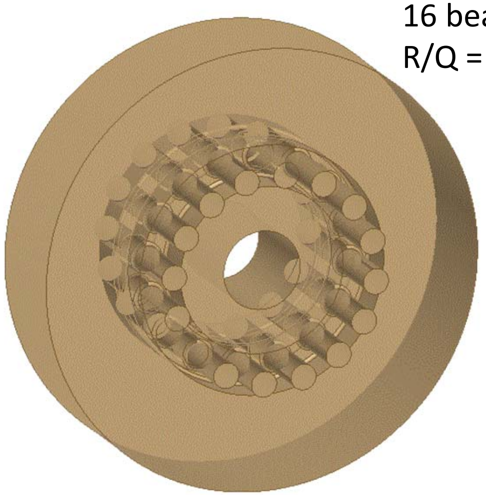


FCC ^{ee} CW, MBK klystron (HEKCW)

HEIKA/HEKCW working team:

I. I. Syratchev (CERN)
II. G. Burt (Lancaster)
III. C. Lingwood (Lancaster)
IV. D. Constable (Lancaster)
V. V. Hill (Lancaster)
VI. R. Marchesin (Thales)
VII. Q. Vuillemin (Thales/CERN)
VIII. A. Baikov (MUFA)
IX. I. Guzilov (VDBT)
X. C. Marrelli (ESS)
XI. R. Kowalczyk (L-3com)

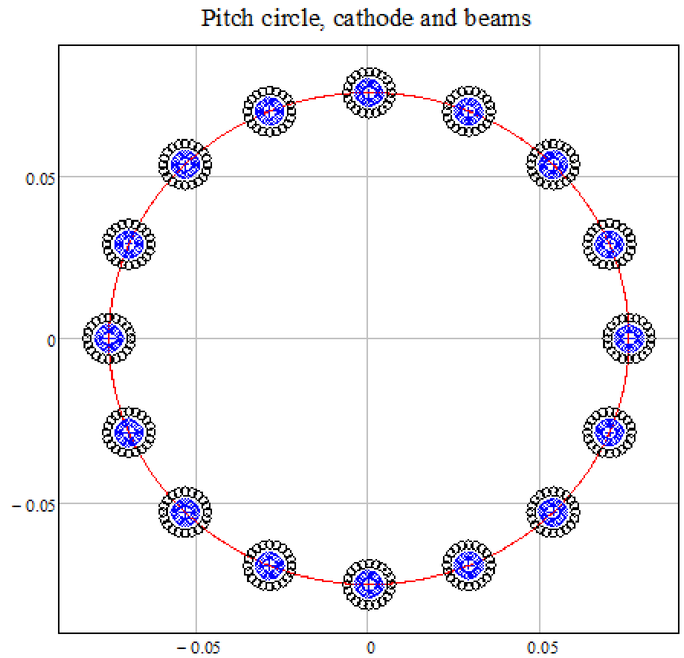
16 beams MBK cavity
R/Q = 22 Ohm/beam



Tube parameters:

- Voltage: 40 kV
- Total current: 42A
- N beams: 16
- µK/beamx10^6 : 0.33
- N cavities: 7
- Bunching method #1: COM

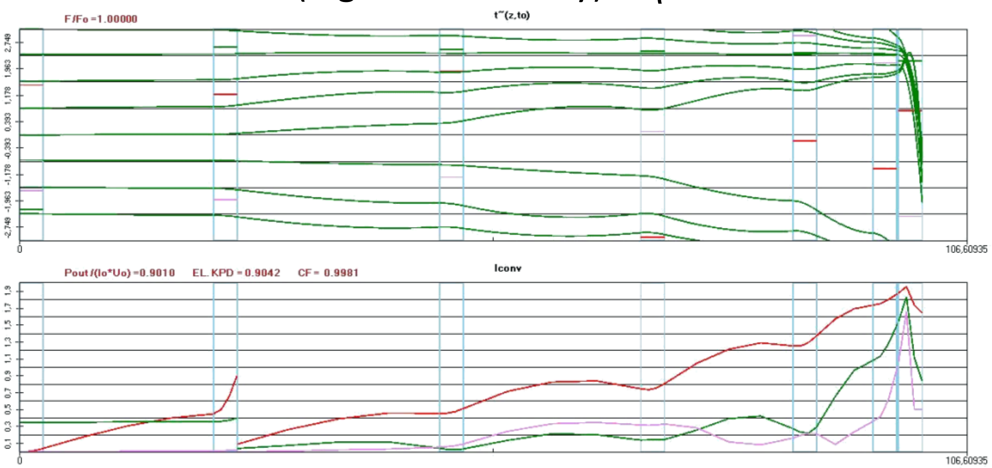
- Cathode loading: 2 A/cm^2
- Beam radius: 3 mm
  - Filling factor 8 mm
- Length: 2.3 m
- Beam circle radius: 75 mm
- Solenoid field (2x): 600 G
- Solenoid radius: 150 mm
- Collector: common
  - Nominal load: 170 kW



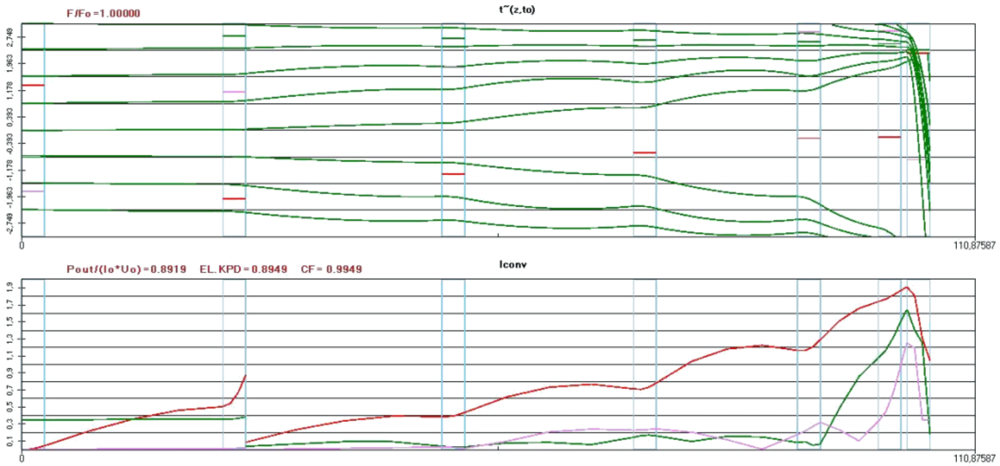
HEKCW RF circuit optimisation

Few tubes were optimised using KlypWin (1D code). Two of them were selected for further study.

HEKCW #11-02 (highest efficiency) η= 90.1%

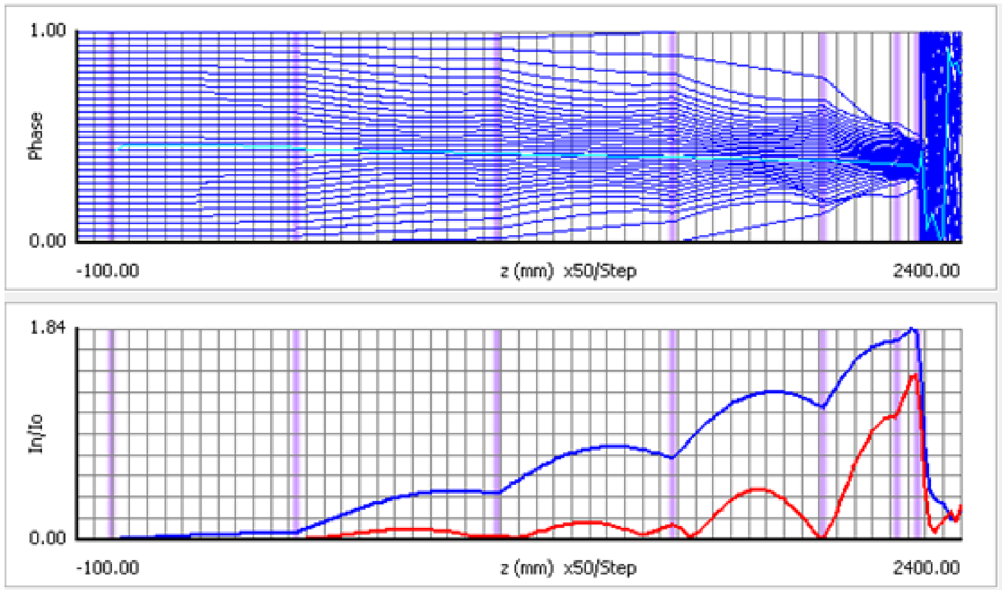


HEKCW #11-07 (‘cleanest’ phase trajectories) η=89.2%

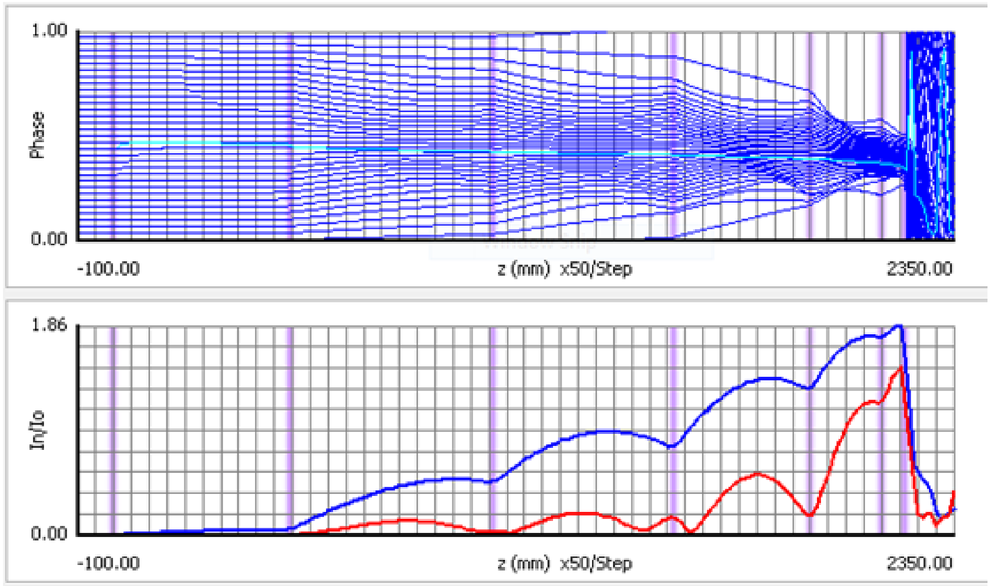


High efficiency confirmed by another non-commercial 1D code AJDisk

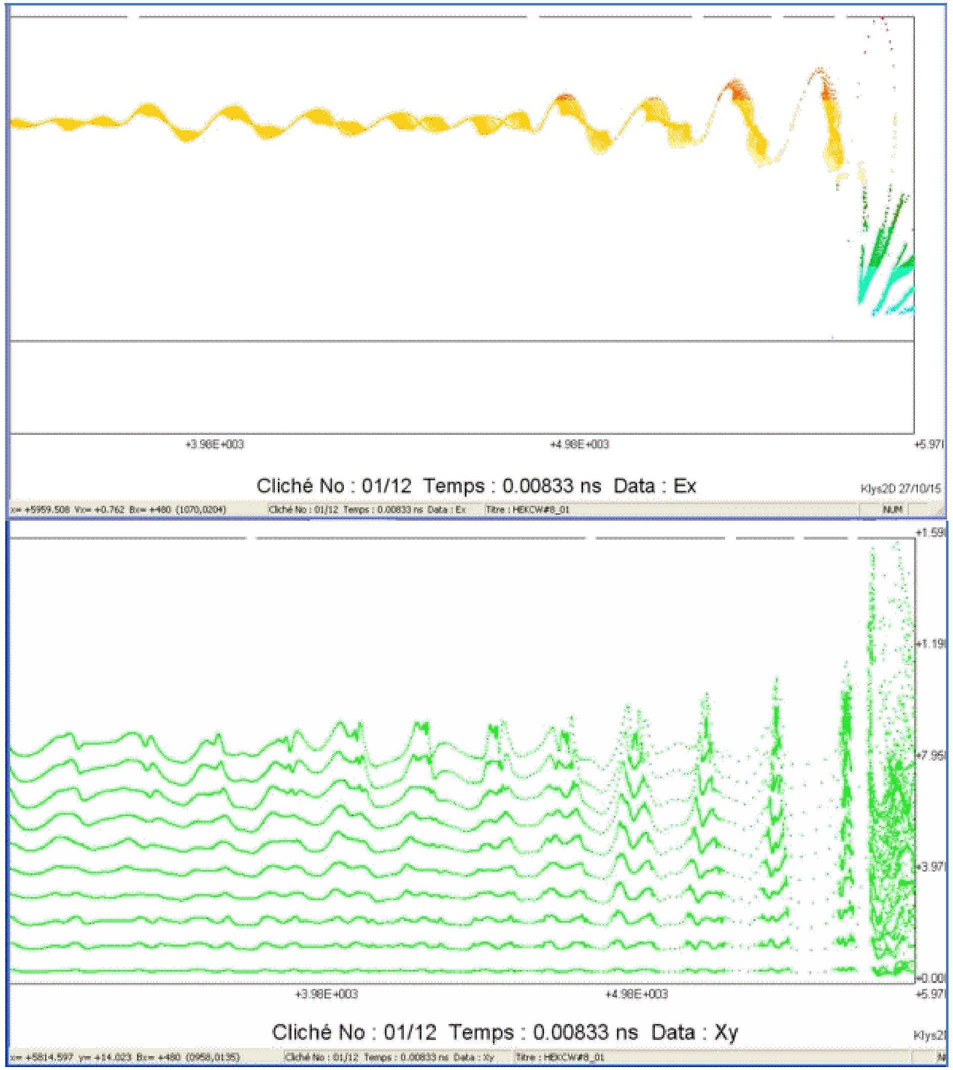
η= 88.0%

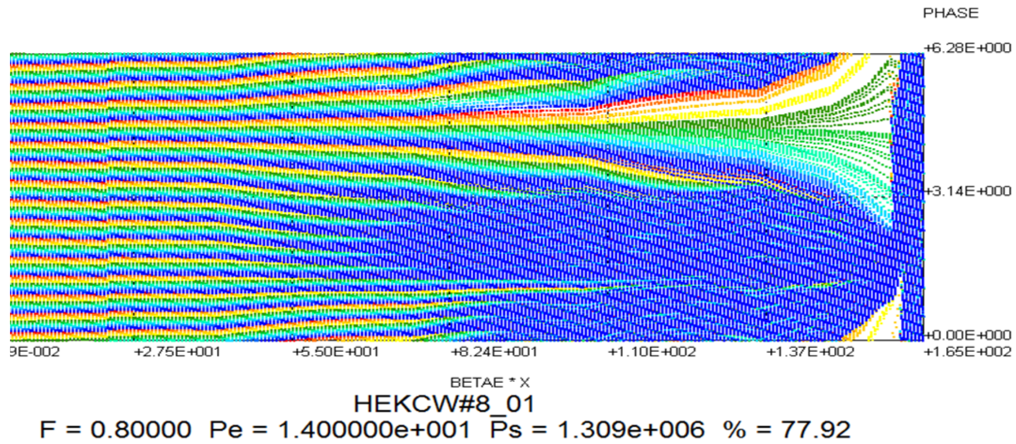


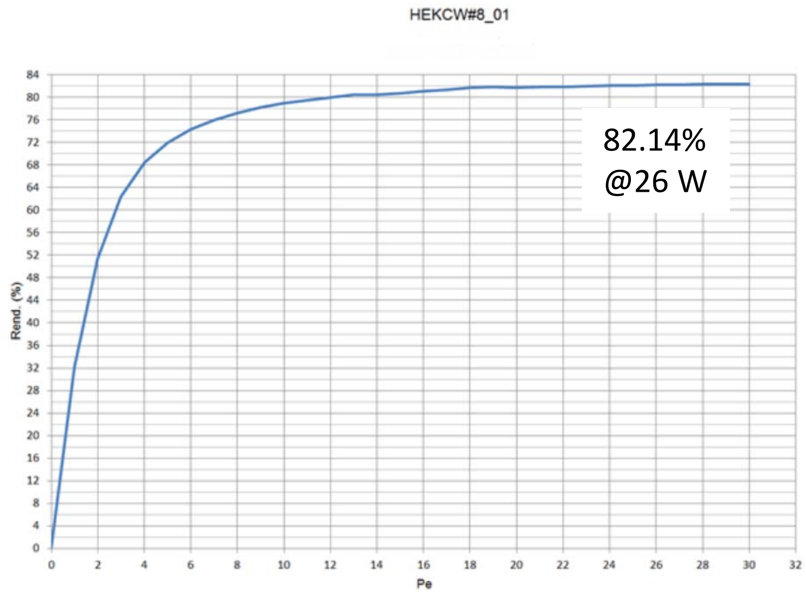
η= 88.5%



The first ‘robust’ (2D) design with 82% RF production efficiency. Klys2D code THALES







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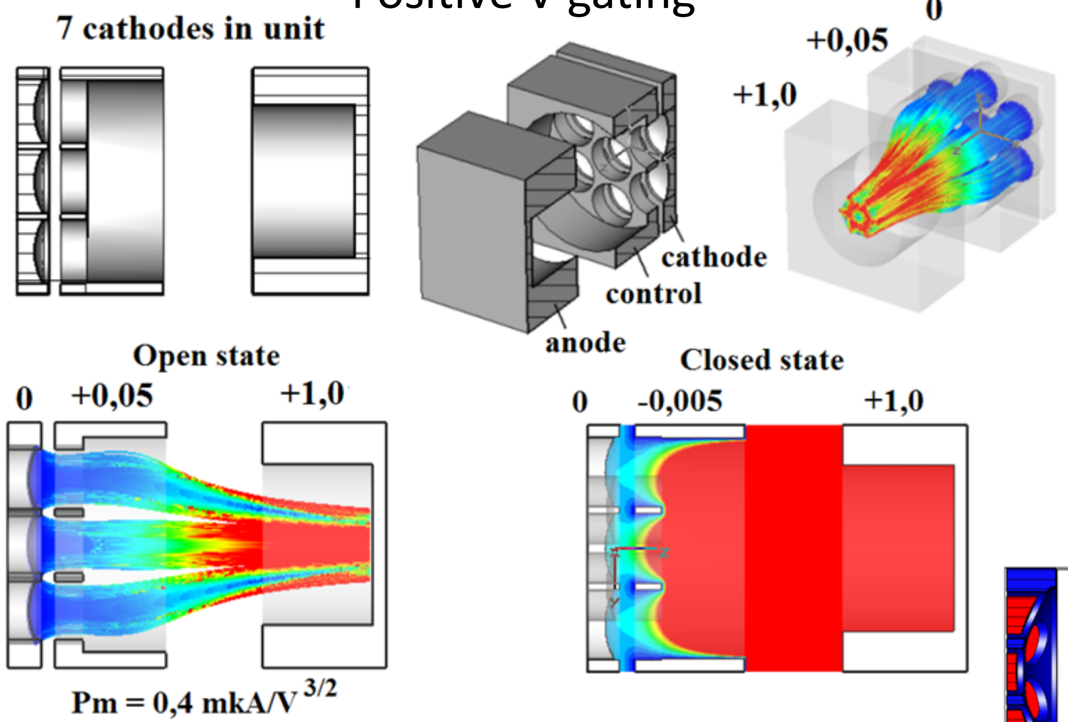
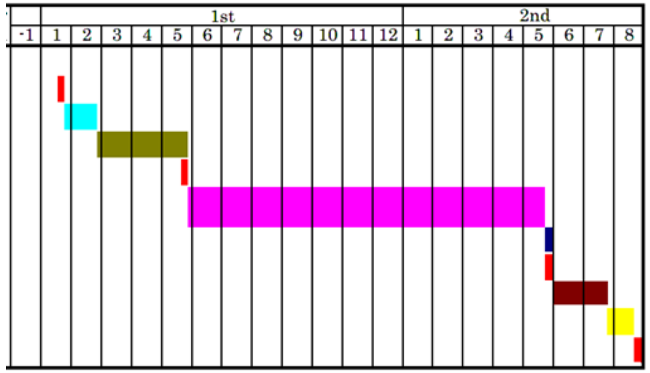
Gated mine-cathode for the HEKCW. Initiative.

Positive V gating

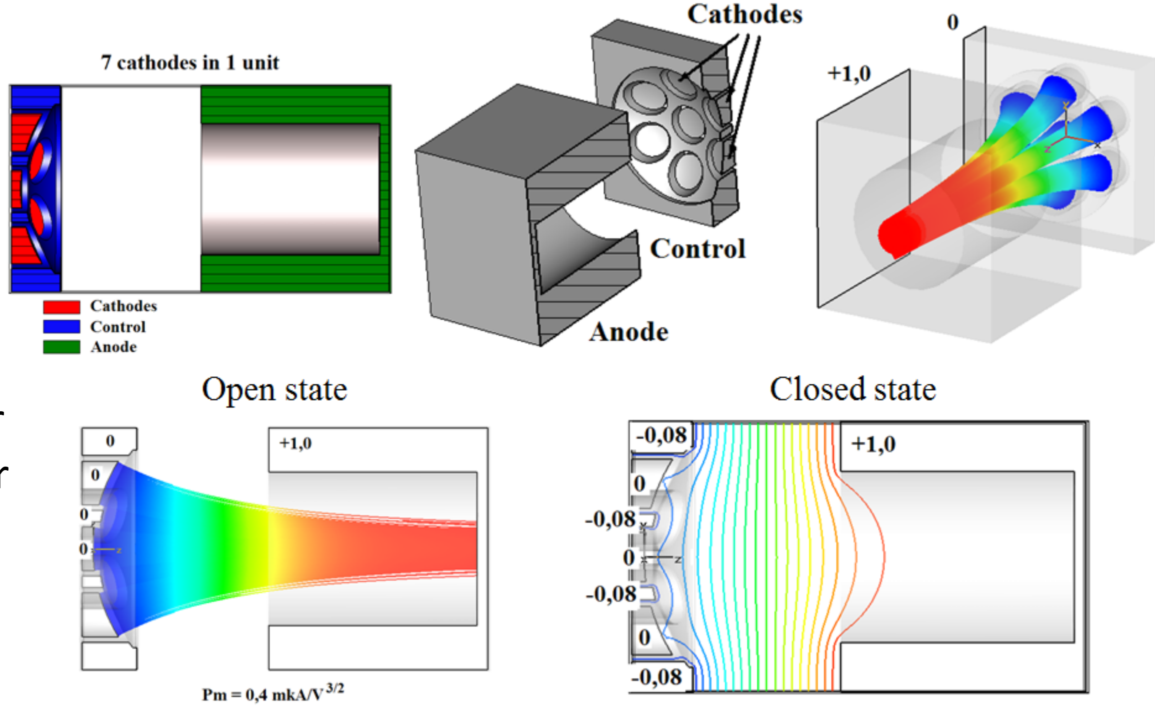


Gate voltage = 0.04 V nominal

Proposal from I Guzilov VDBT, Moscow



Negative V gating

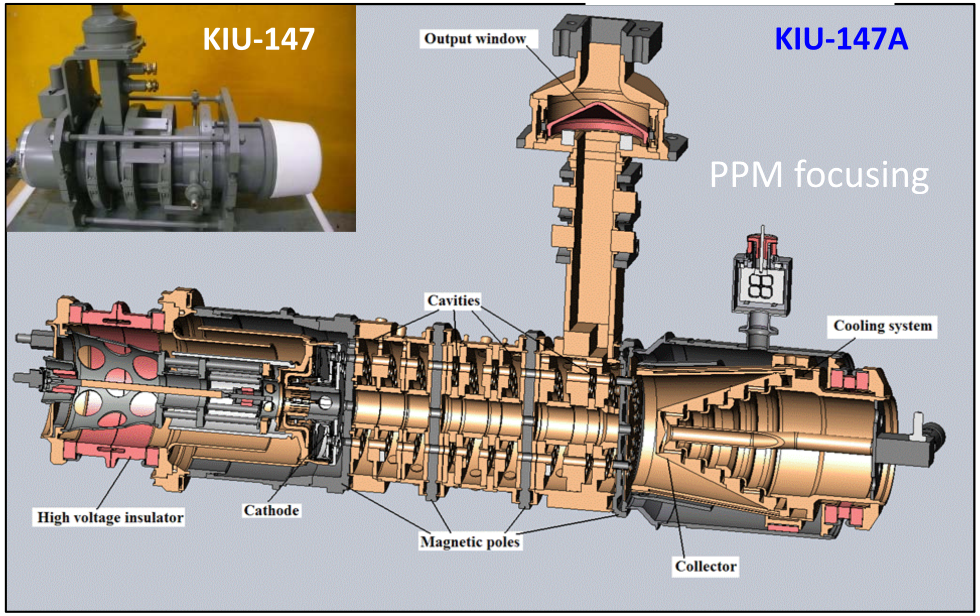


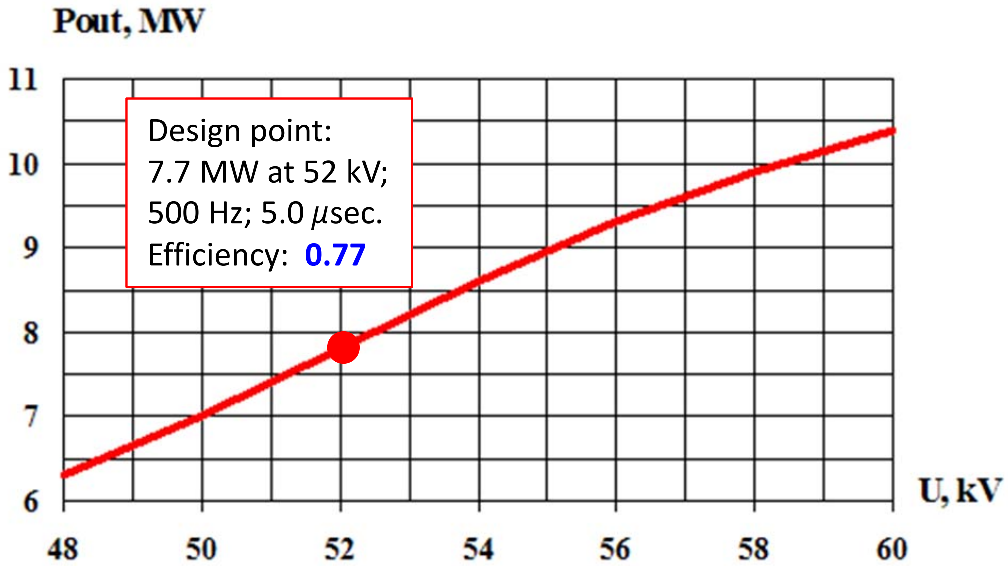
Gate voltage = 0.08 V nominal

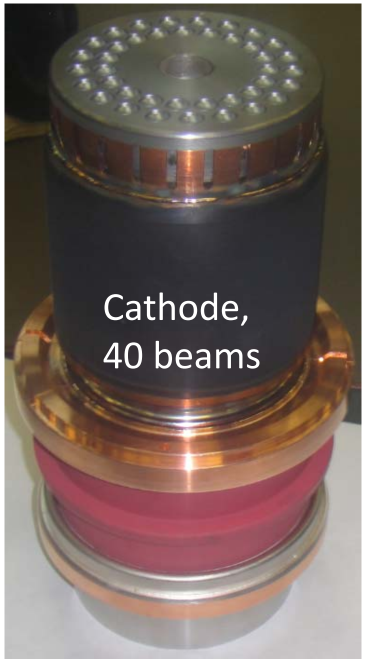
- For CW tube, gated cathode is an effective way for fast protection of the collector. Thus, the collector can be designed for the nominal Power (170 kW)
- For the pulsed tube it allows to eliminated the HV switching system in the modulator.

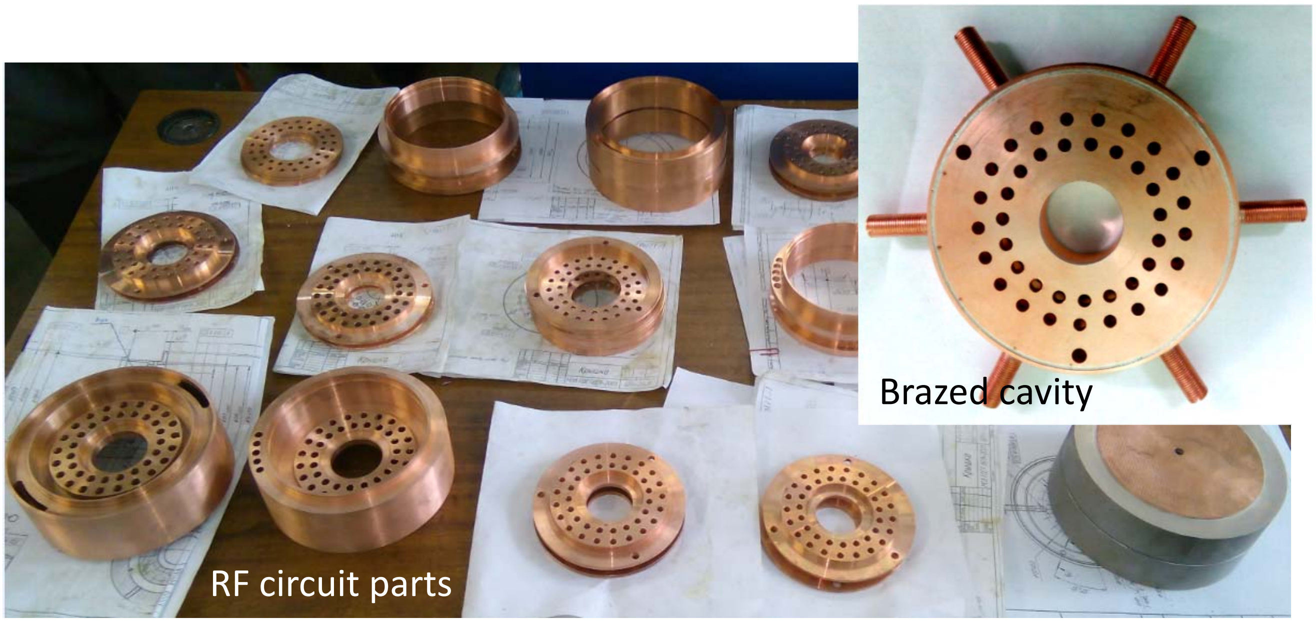
COM(BAC) technology demonstrator tube. To be tested in November 2015.

JSC "Vacuum device's basic technologies", Moscow, Russia

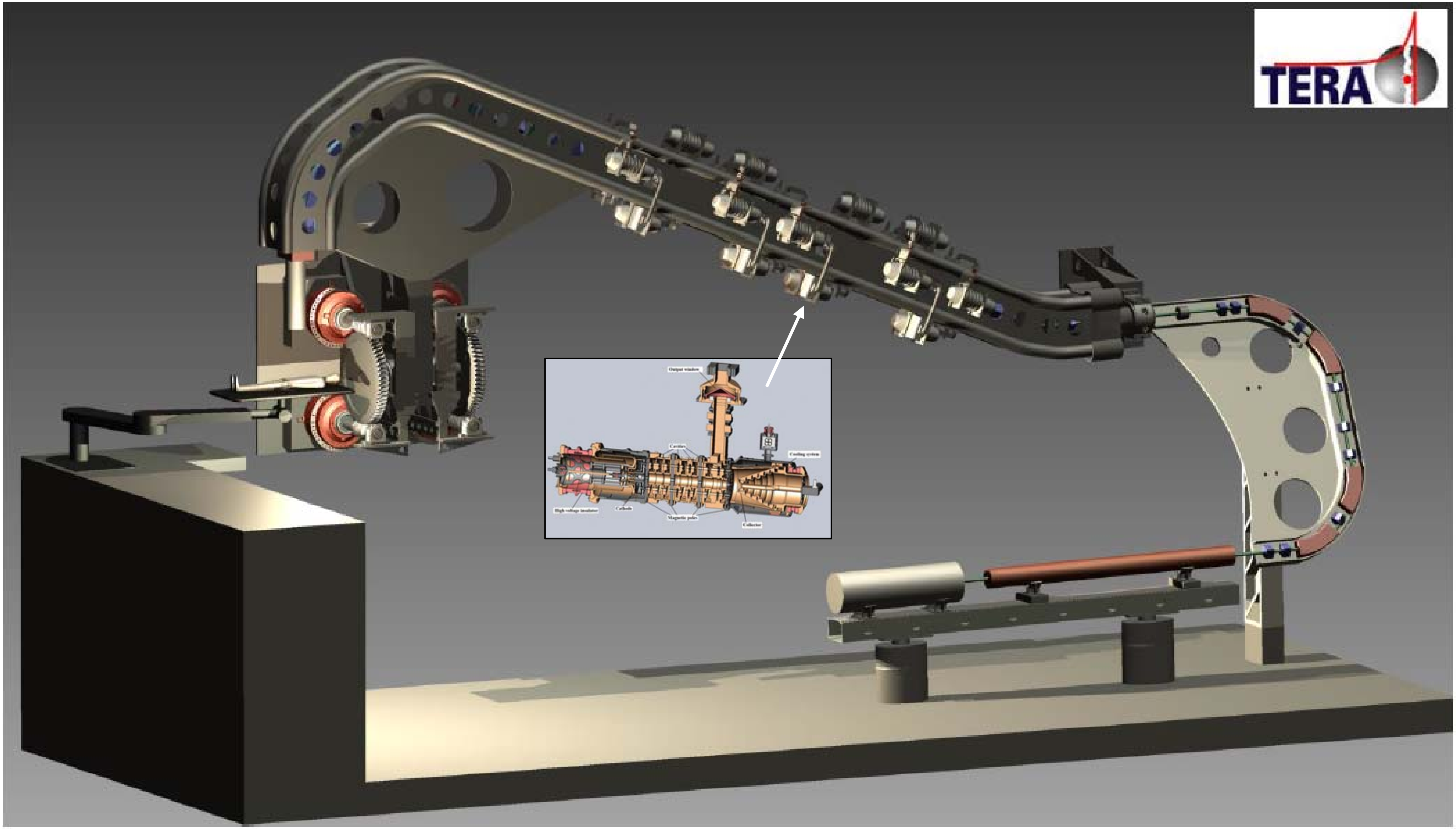








TULIP- high gradient compact proton linac for cancer therapy



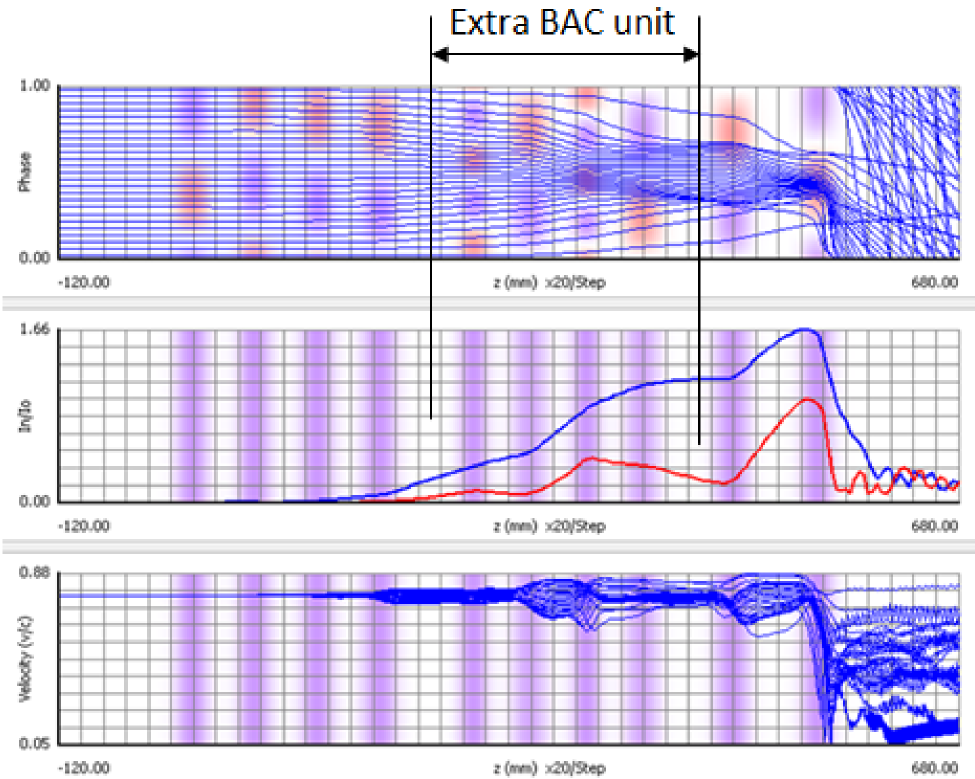
Courtesy of M. Vaziri, TERA Foundation

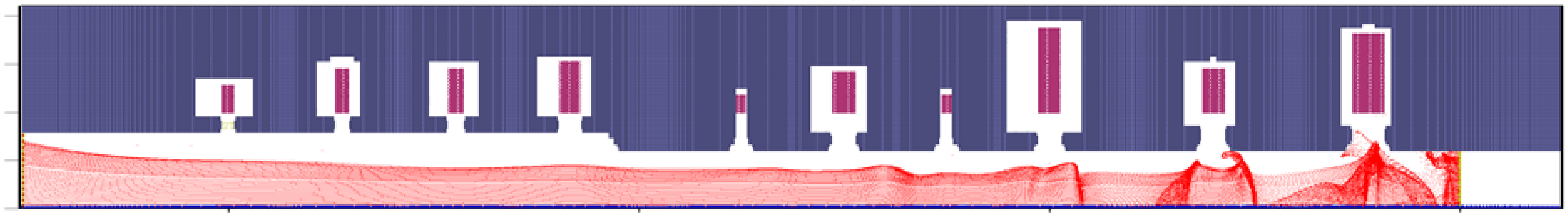
Klystron retrofit activity at SLAC (A. Jensen)

The BAC bunching technology was studied at SLAC in attempt to improve the performance of existing S-band SLAC klystron 5045. This is the most mass-produced (>800) high peak RF power (65 MW) tube. First tests are scheduled to be done in spring 2016.

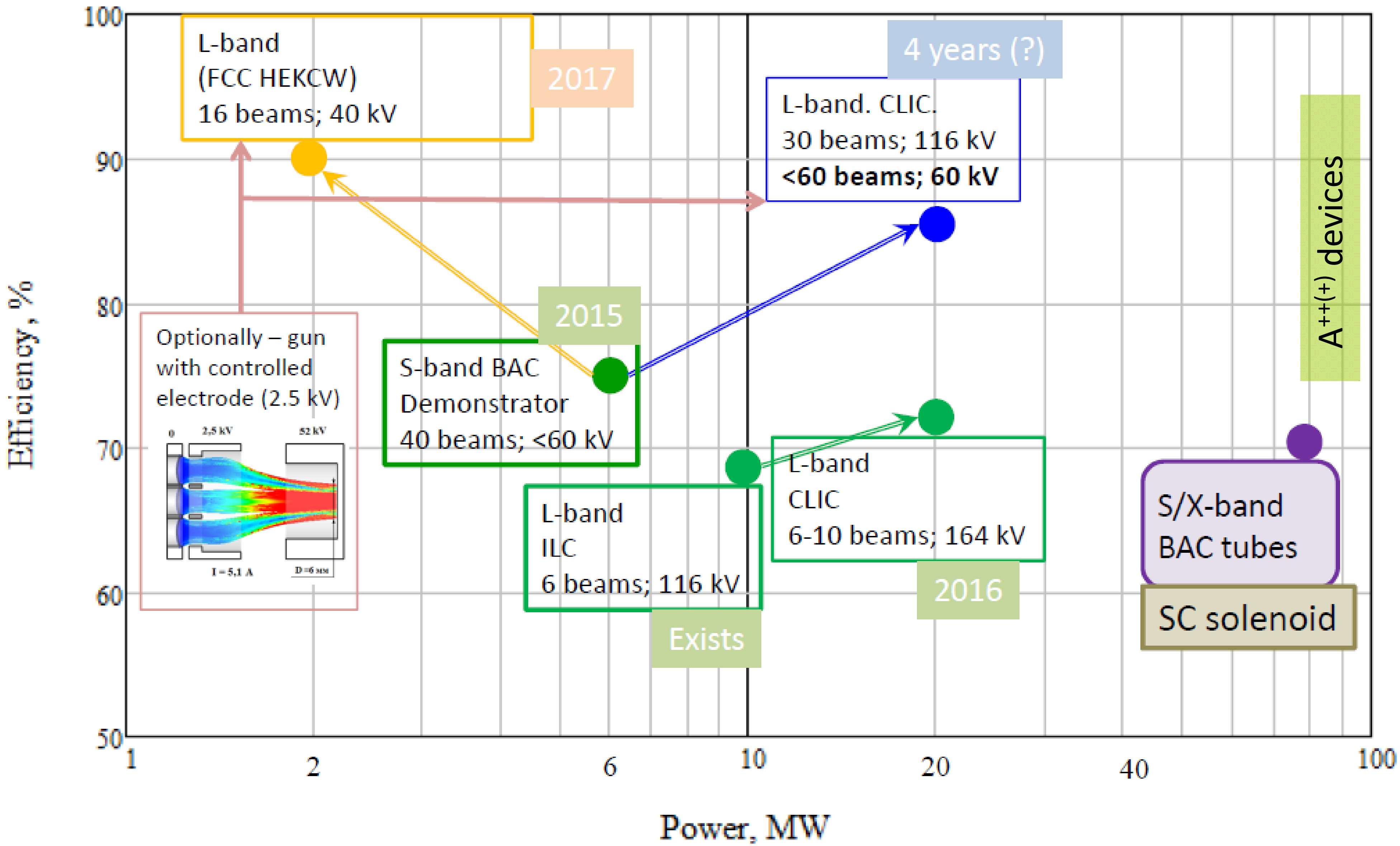
Typical 5045 Operating Parameters

Operating Parameter	Value	High efficiency
Frequency	2.856 GHz	
Beam Voltage	350 kV	
Perveance	2.0 $\mu A/V^{1.5}$	
Peak Output Power	65 MW	92.5 MW
Average Output Power	41 kW	
RF Pulse Width	3.5 μs	
Pulse Rep. Rate	180 Hz	
Gain	50 dB	
3 dB Bandwidth	20 MHz	
Saturated Efficiency	45%	62.5%
Cathode Current Density	8 A/cm^2	





Strategy for high-efficiency high RF power klystron development



I. Syratchev, October 2016, Energy for Sustainable science, Hamburg.

CLIC Workshop 2016

18-22 January 2016
CERN
Europe/Zurich timezone

HEIKA day will be held on Thursday, January 21, 2016.
This time we decided to include the new subject: The very high efficiency IOT.