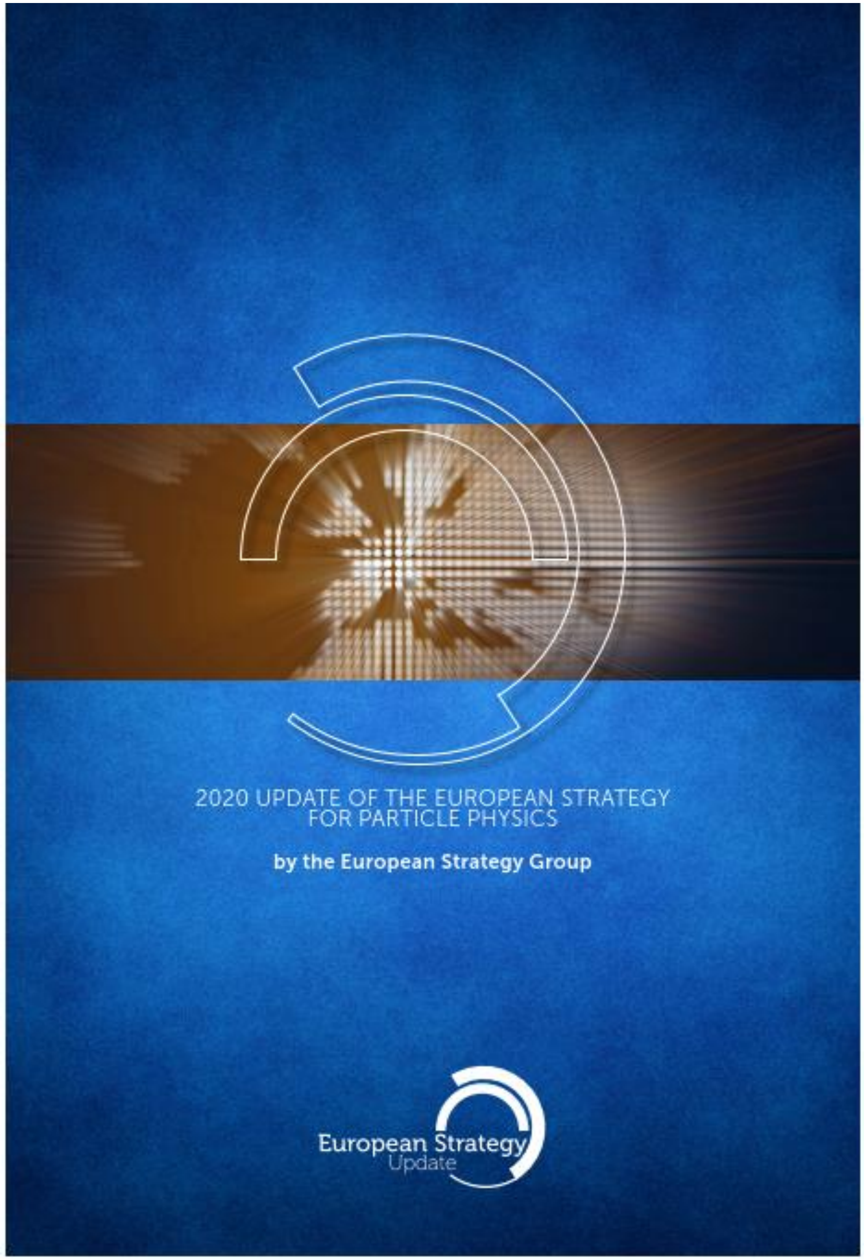
Low Emittance Rings workshop 2024
Feb 13 – 16, 2024
CERN

High Efficiency Klystrons

Highly efficient RF power sources

I. Syratchev for CERN & ULAN HE klystron team



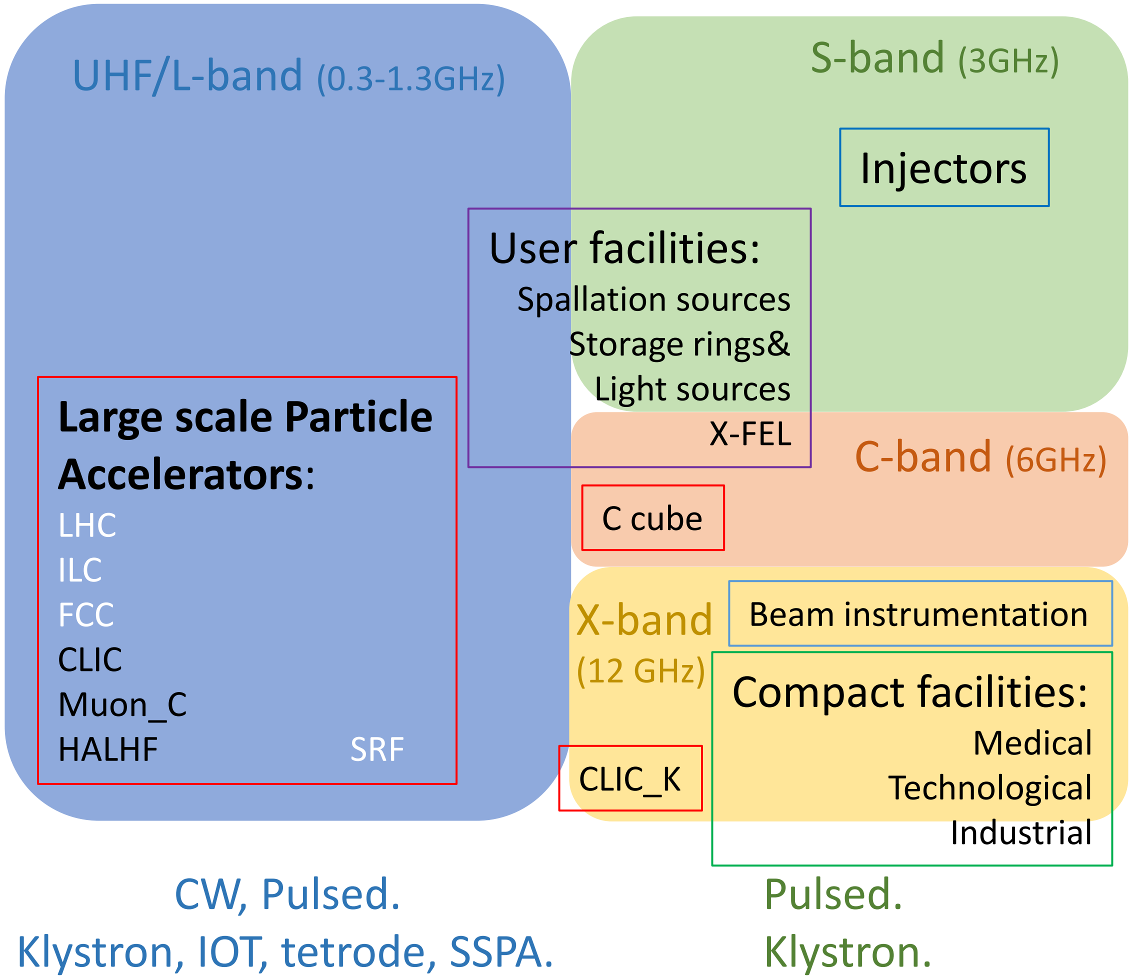
7 Environmental and societal impact

A. The energy efficiency of present and future accelerators, and of computing facilities, is and should remain an area requiring constant attention. Travel also represents an environmental challenge, due to the international nature of the field. ***The environmental impact of particle physics activities should continue to be carefully studied and minimised. A detailed plan for the minimisation of environmental impact and for the saving and re-use of energy should be part of the approval process for any major project. Alternatives to travel should be explored and encouraged.***

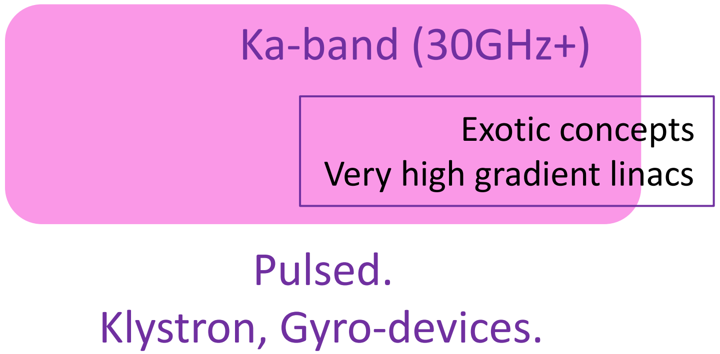
C. Particle physics has contributed to advances in many fields that have brought great benefits to society. Awareness of knowledge and technology transfer and the associated societal impact is important at all phases of particle physics projects. ***Particle physics research centres should promote knowledge and technology transfer and support their researchers in enabling it. The particle physics community should engage with industry to facilitate knowledge transfer and technological development.***

https://europeanstrategy.cern/home

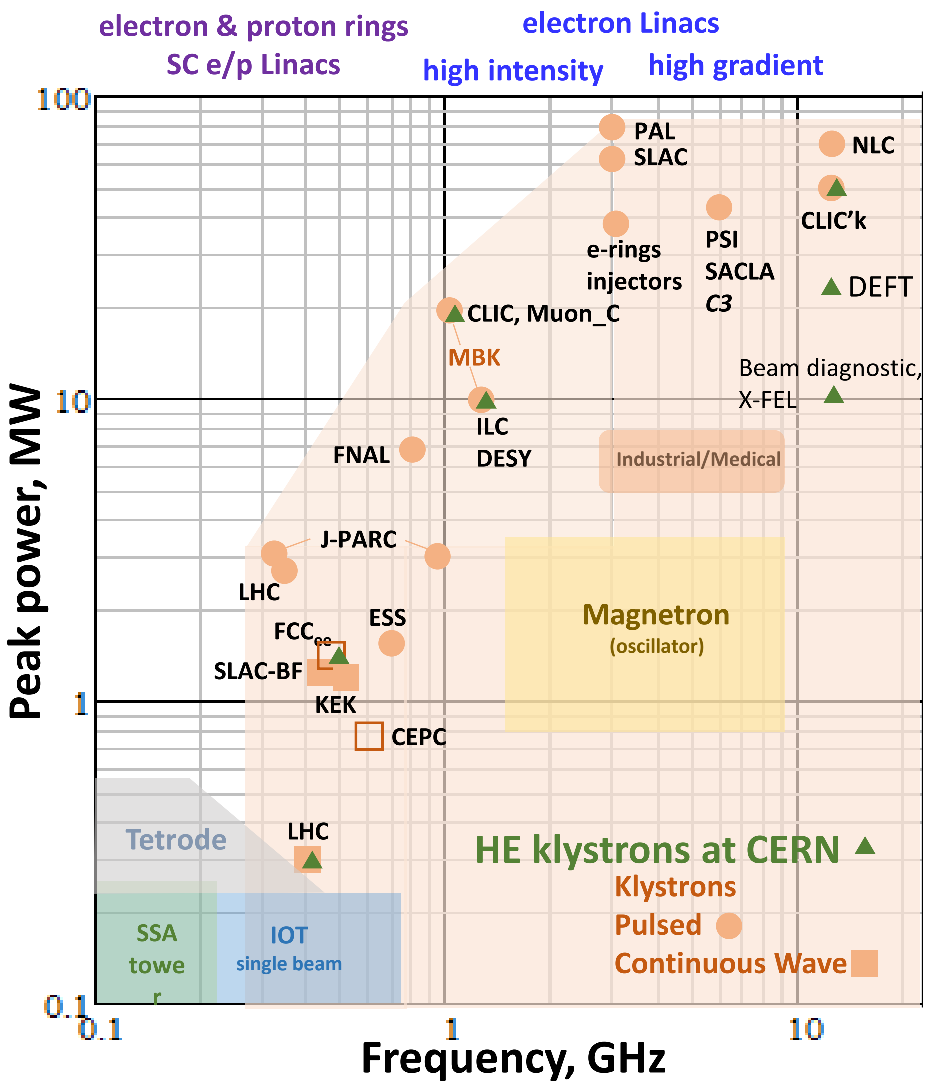
RF power sources for particle accelerators



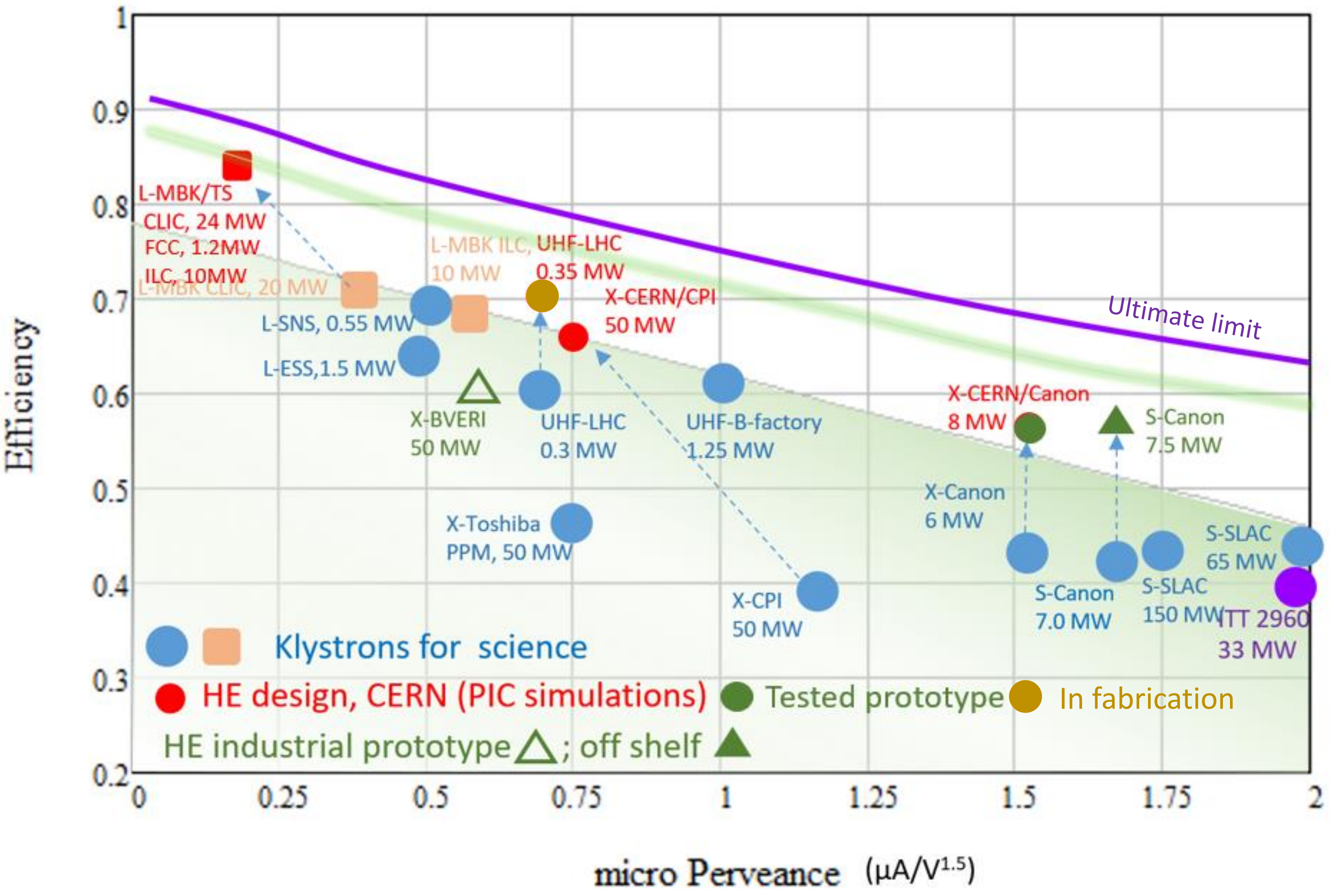
- **Large scale particle accelerators** can be operated with vast diversity of RF power sources.
- The actual choice of the RF source type will be driven by the practical consideration : tunnel integration, spatial power density, cost/W and Efficiency.



The klystron is a key element of almost all particle accelerators.



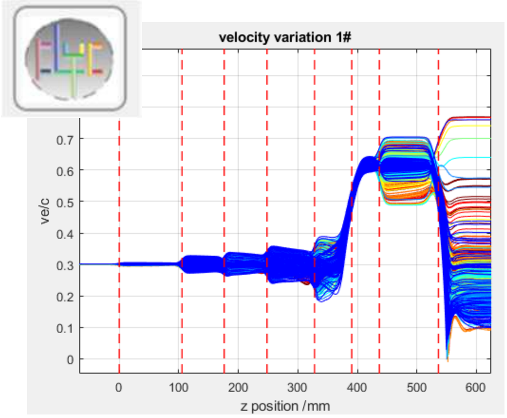
High Efficiency klystrons project at CERN is targeted to improve efficiency and performance of these devices for various applications.



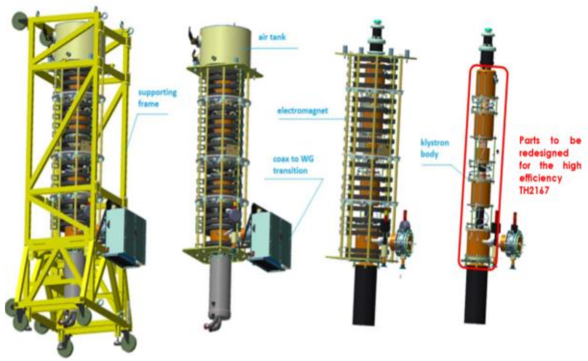
High Efficiency Klystrons

High Efficiency klystrons activity was initiated at CERN in 2014. In 2021 it was transformed into a CERN's **project**.

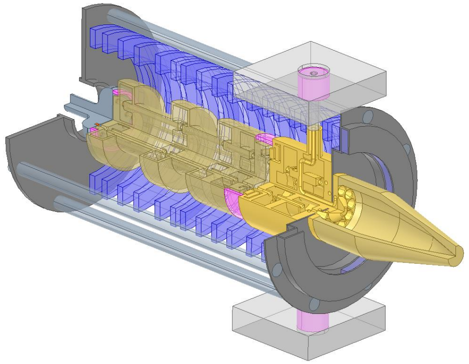
Objectives: Development, design, fabrication and testing of new HE klystrons for various accelerators projects in **collaboration with industry**.



In fabrication



In development



delivered

First commercial X-band 10 MW HE klystron.
CERN-Canon collaboration

Task 1: Design & simulations

- Maintenance and distribution of the CERN made klystron code KlyC.
- High level expertise in using commercial tools like CST PIC., HFSS etc.

Task 2: HE HL-LHC 400 MHz klystron

- Retrofit upgrade of Thales klystron (60% to 70%) in close collaboration with industry.
- A base line option for HL-LHC.

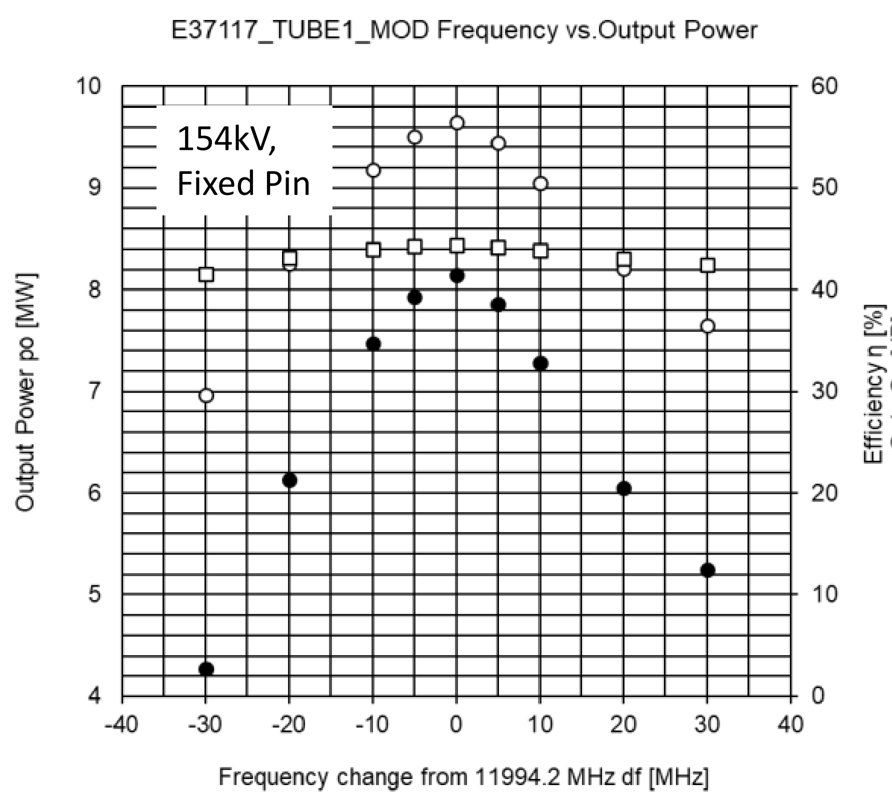
Task 3: Novel two-stage klystron technology with 80%+ RF production efficiency

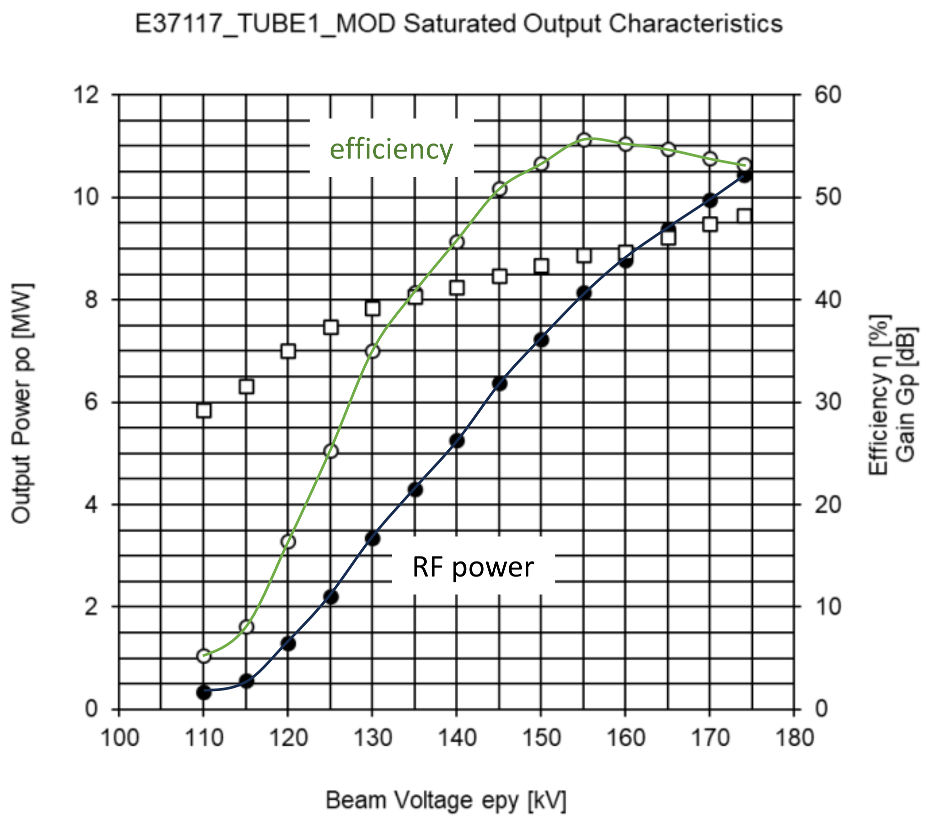
- Design, fabrication and testing of the 400 MHz 1MW CW klystron for FCC in collaboration with industry.
- Promote this new technology towards CLIC, ILC and Muon_C.

Task 4: High efficiency X-band klystrons in the power range 10-50MW

- Strong Collaboration with industry (Canon, CPI and Thales).
- Important for multiple projects (CompactLight, DEFT, EUPRAXIA etc.).
- Great show case for CERN's technology and contribution to worldwide society.

The klystron was successfully tested at Canon in up to 10.5MW.





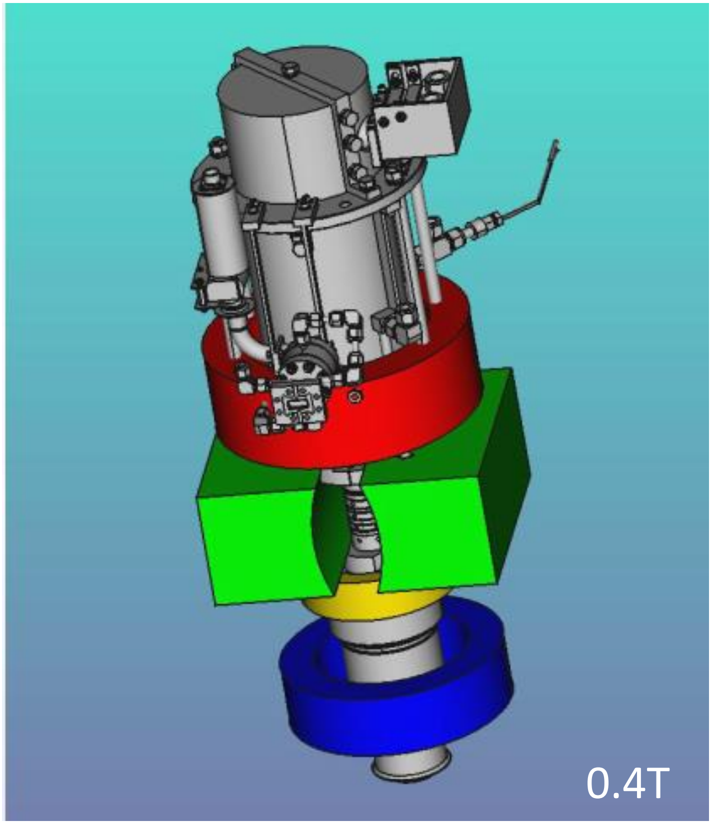
- At operating frequency klystron showed **57%** (cf. 42%). That corresponds to **35%** RF peak power increase compared to the original Canon tube at the same operating voltage.
- Tube reached 10.5MW. Compatible with existing Xbox#3 ScandiNova modulator (with 175kV max recommended).
- In a range of RF power levels from 6MW to 10.5 MW the klystron is 50%+ efficient and can be used for different application in this range by adjusting modulator type/voltage.
- **The tube is commercially available.**

RF power source **system** efficiency improvement (DC focusing magnets) in pulsed devices.

HITACHI KEK CERN

Superconducting MGB2 (28^0K) solenoid, with the 50 MW X-band klystron, installed on the modulator in XBOX#2.
Power consumption reduced from 20kW to 3kW.

ELYTT ENERGY High Efficiency Klystrons HEK iFAST

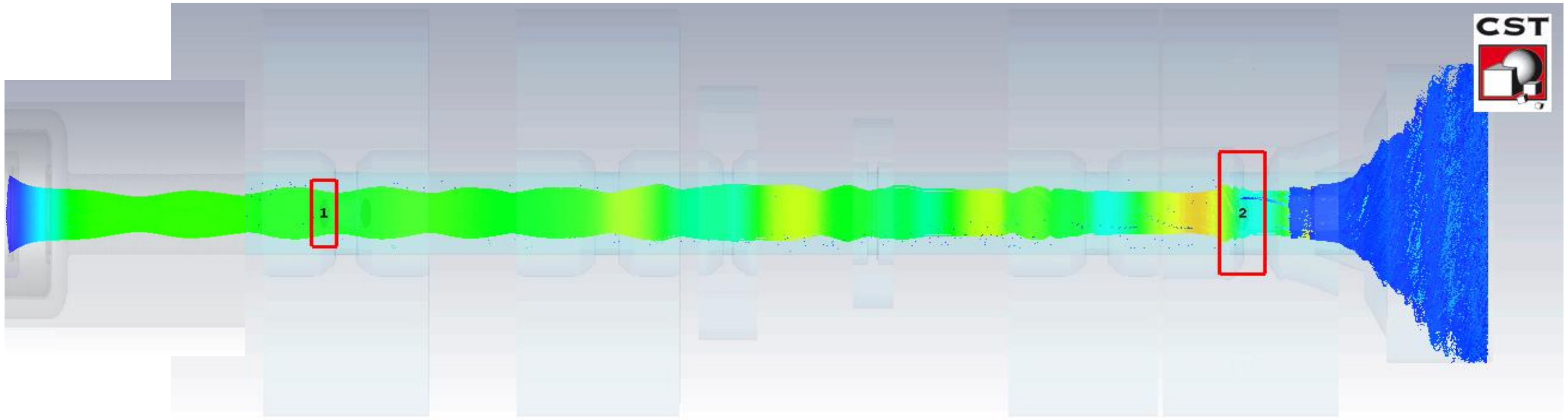


Permanent magnets **solenoid** prototype for 10 MW X-band klystron. In development within IFAST grant.
Power consumption reduced from 10kW to 0kW

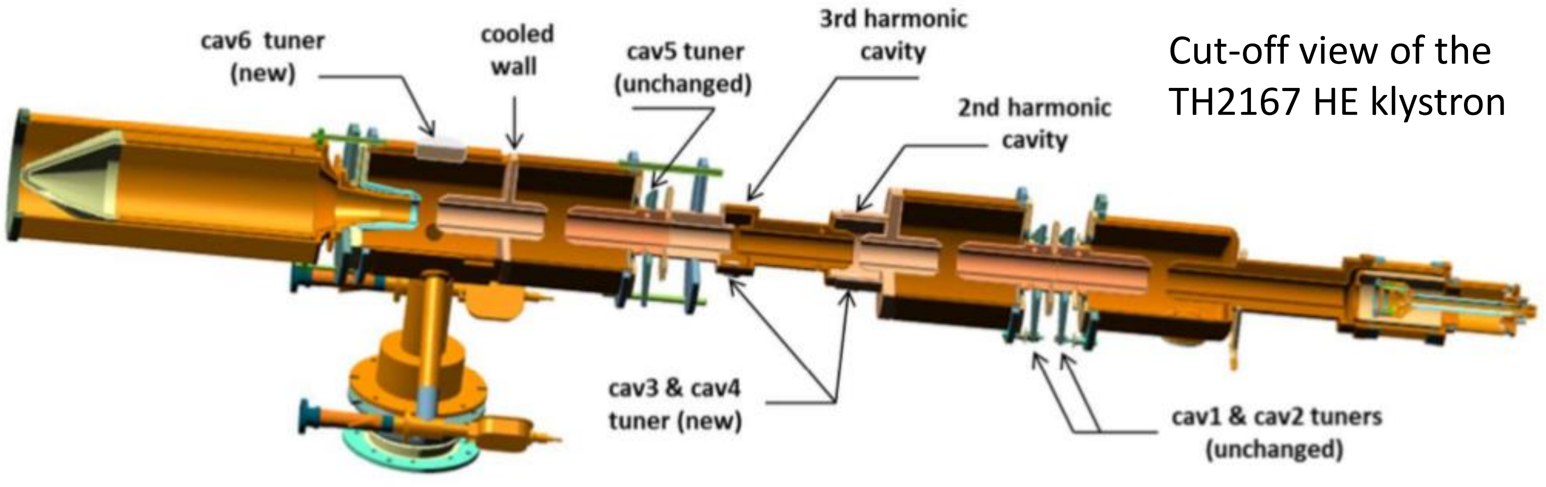
Retro-fit High Efficiency (70%) 350kW, 0.4 GHz CSM LHC klystron upgrade for HL-LHC.

(in collaboration with Thales)

3D PIC full simulations



	LHC/CSM	LHC/Thales
Frequency, GHZ	0.4	0.4
Beam power, MW	0.5	0.5
Perveance,	0.72	0.72
RF power, MW	**0.35**	0.30
Efficiency, %	70	60

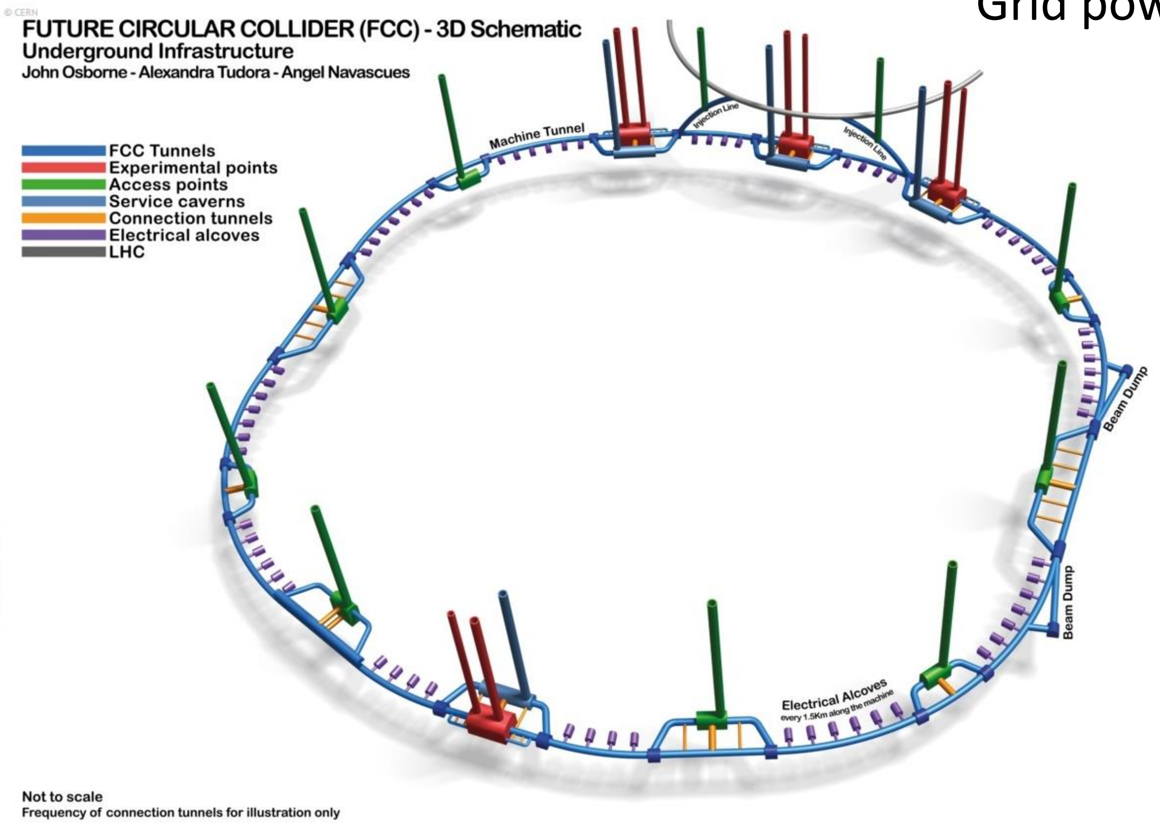


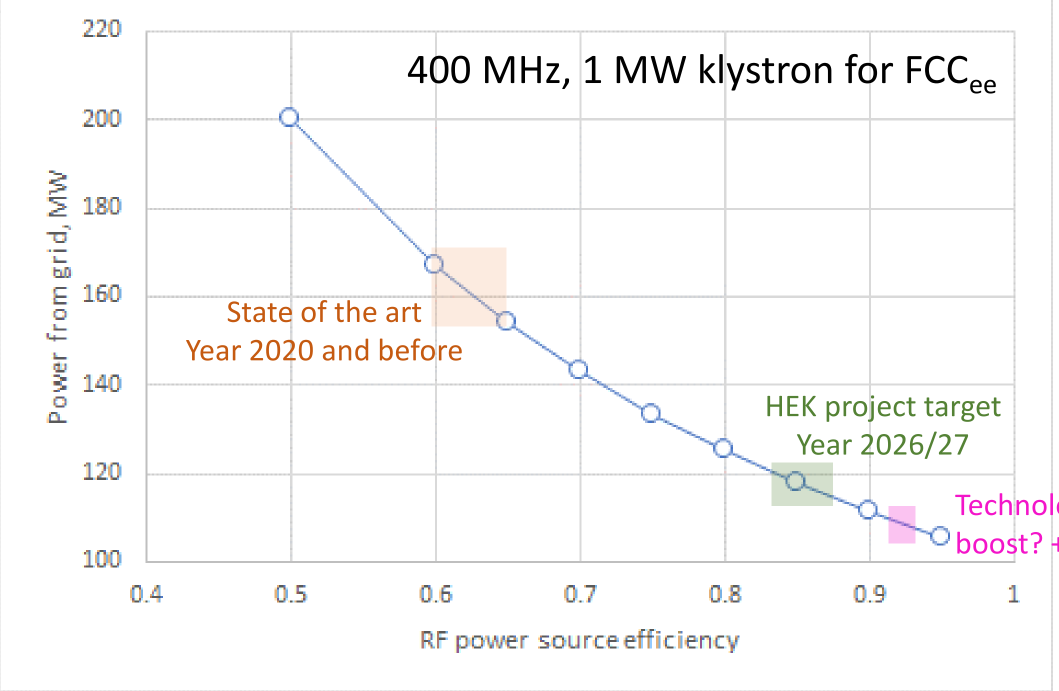
Cut-off view of the TH2167 HE klystron

FAT is scheduled to May-June 2024.

THALES

Grid power needs for the large-scale HEP Accelerators.





To operate FCC$_{ee}$, **100 MW** Continues Wave RF power is needed to compensate for the energy loss into synchrotron radiation.

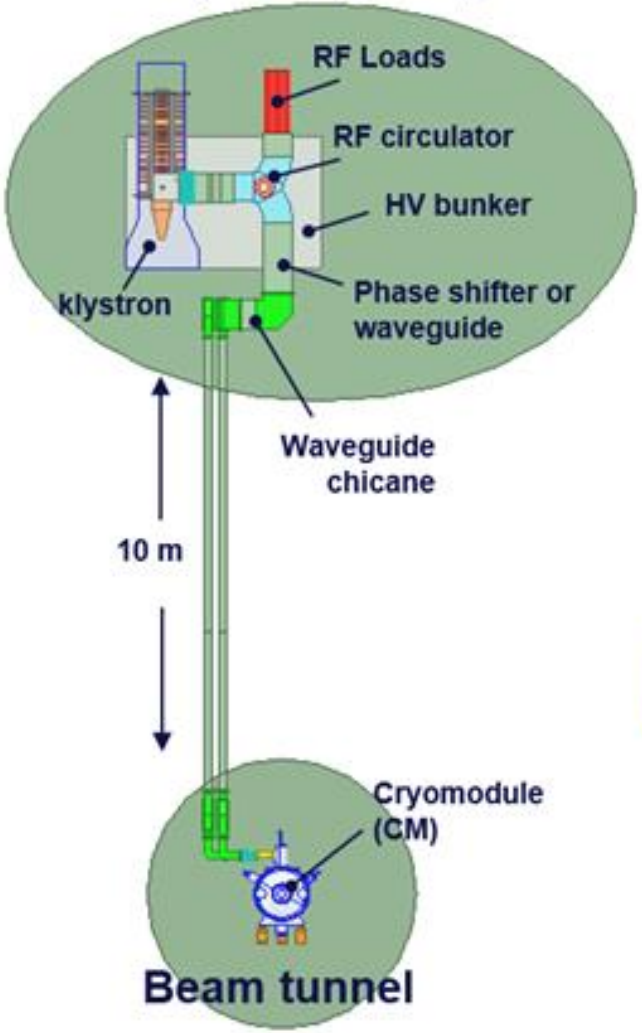
Improving klystron RF efficiency from 65% in existing commercial devices to 85% in the new HE tubes will:

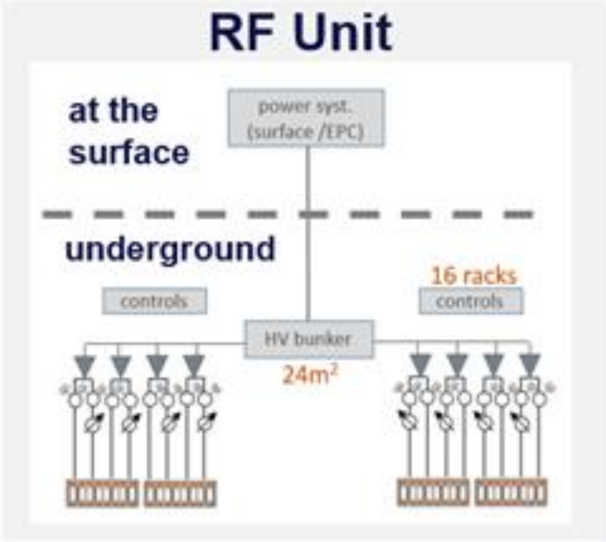
- Save 32.2 MWh -> 253 GWh (7000h/year) -> **2.53TWh over 10Y.**
- Reduce cost and power consumption of power converters and cooling system (environmental impact).

FCC Accelerator tunnel and klystron gallery

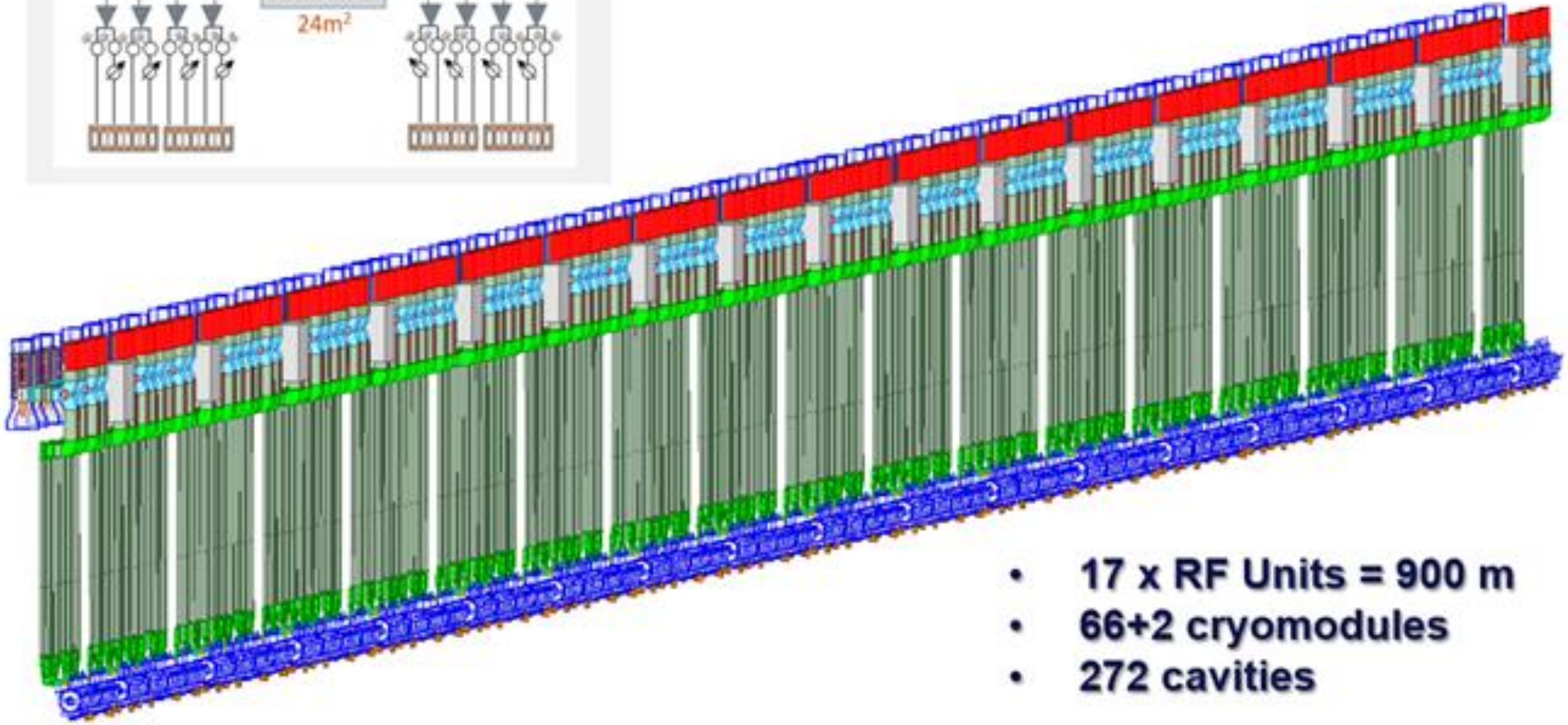
RF system configuration for the Higgs factory

Klystron gallery





- To reduce tunnel cost (cross-section) and RF power sources/HV integration in the tunnel, compact (~**3m long**), vertical klystron solution is required.
- Operating tubes at moderate HV (**60kV**) is beneficial to avoid oil tanks in the tunnel (**MBK option**).



- 17 x RF Units = 900 m
- 66+2 cryomodules
- 272 cavities

I. Syratchev, LER WS, CERN, February 2024

Two-Stage Multi Beam Klystron (TS MBK) technology in UHF/L-band.

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:

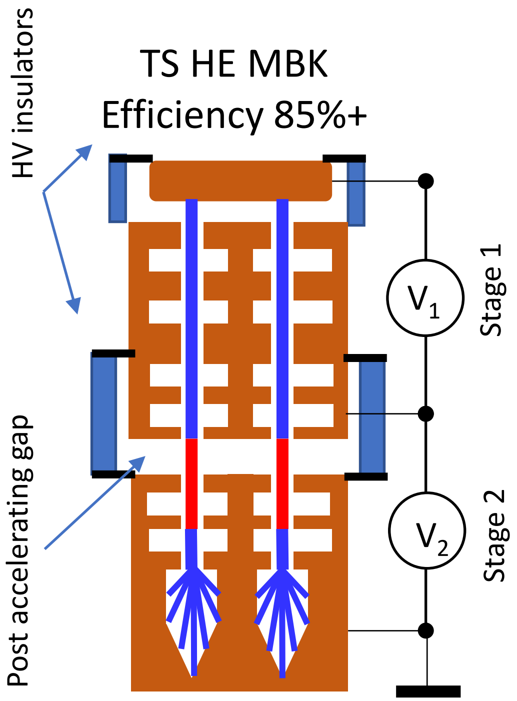
1. For pulsed tubes, the second HV stage can be operated in DC mode. Thus, simplifying the modulator topology. (cost/volume) and increasing the modulator efficiency.
2. Simplified feedback for the first stage pulsed voltage. Improved klystron RF phase and amplitude stability.

Drawbacks:

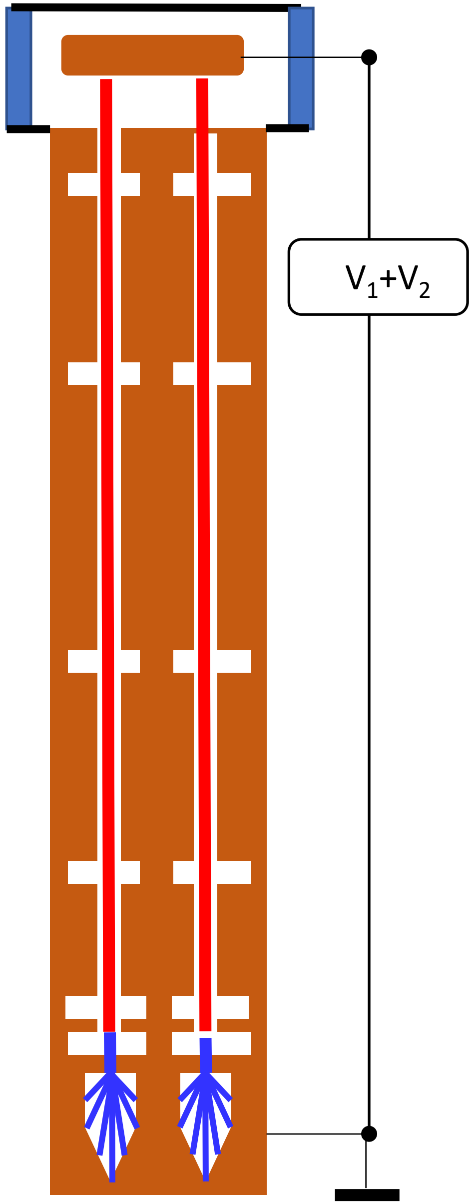
1. Reflected electrons from the output cavity and collector shall be **avoided at any cost.**
2. RF radiation into DC gap must be sealed.
3. Requires special HV isolated RF feedthrough to inject RF signal into input cavity.
4. Large bore (∅400mm) ceramic insulator on the 2nd stage.

GOOD FOR:

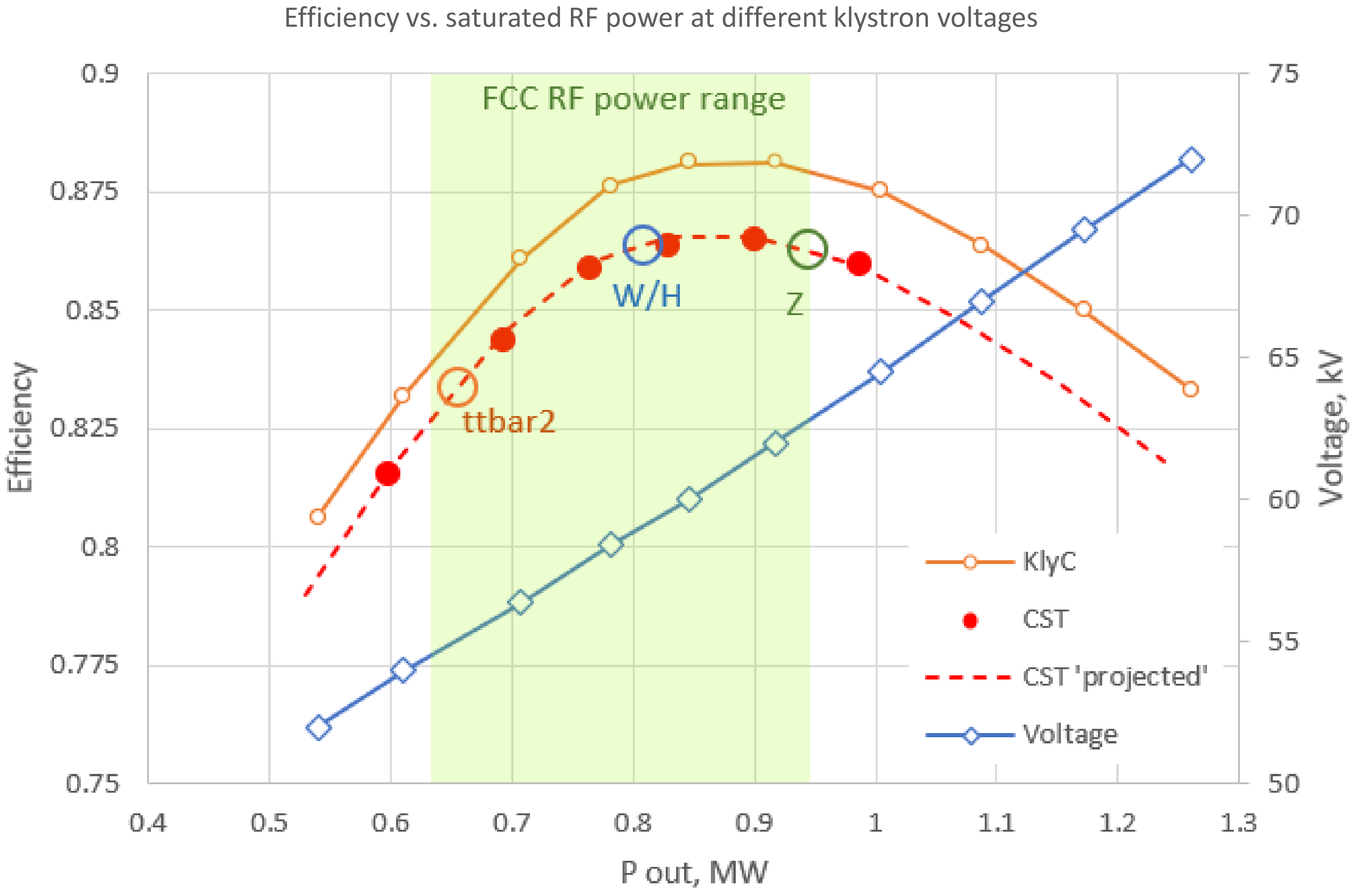
TS HE MBK
Efficiency 85%+



Commercial HE MBK
Efficiency 65%

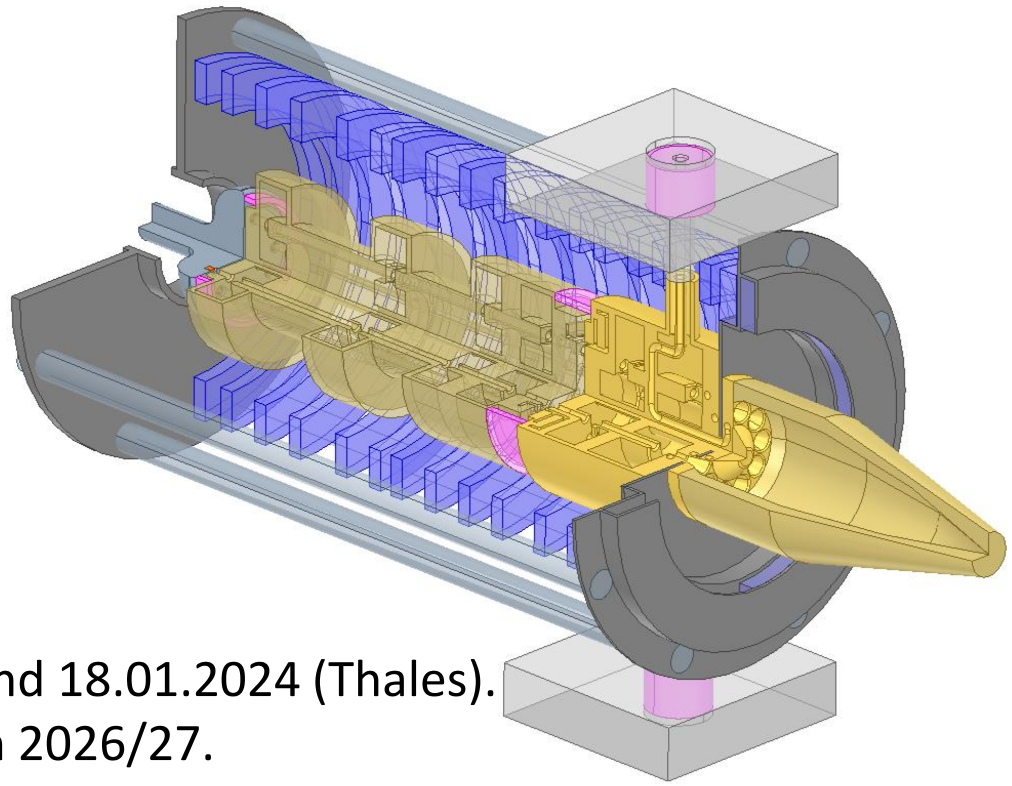


400 MHz, 1MW HE Two-Stages MBK for FCC_{ee}. Design performance summary.



Featured:

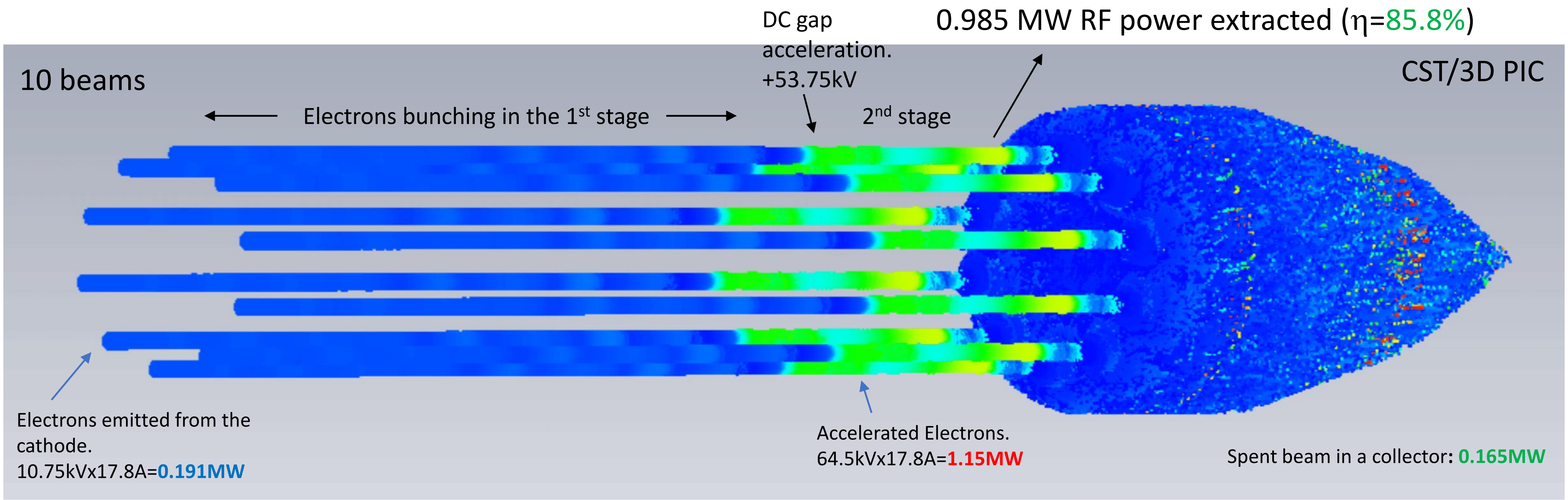
- **Very efficient**. 86% @ Z,W,H and 83% @ ttbar2.
- **Compact**. Total length <3m.
- **Low Voltage**. Up to 64kV @ 1 MW.
- **High RF power gain**. 43dB @ 1MW.
- **Broadband**. 3.5 MHz @ -1dB.
- **Robust**. Can handle mismatch up to -15dB.

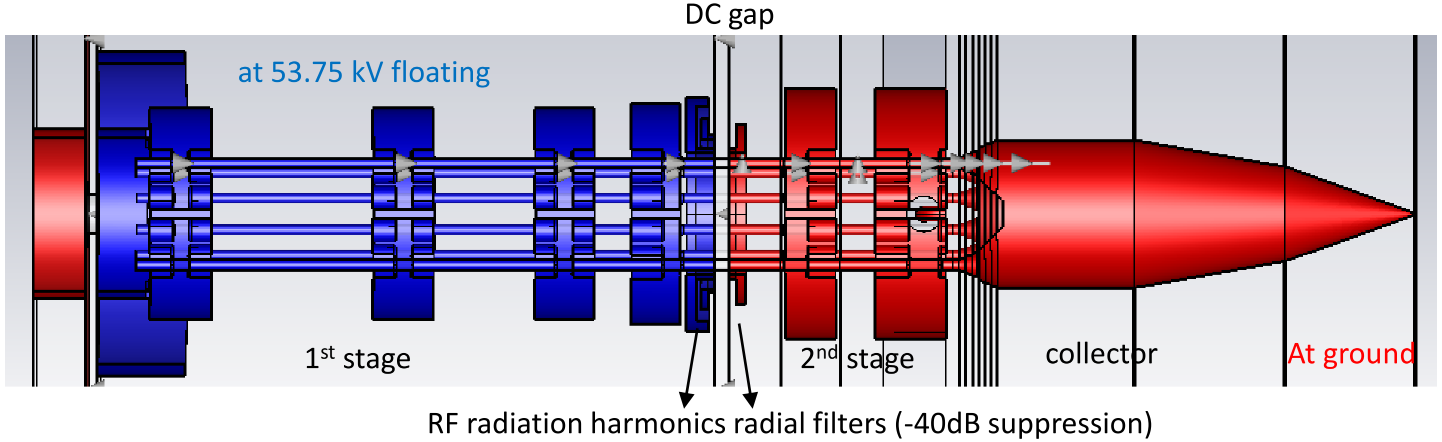


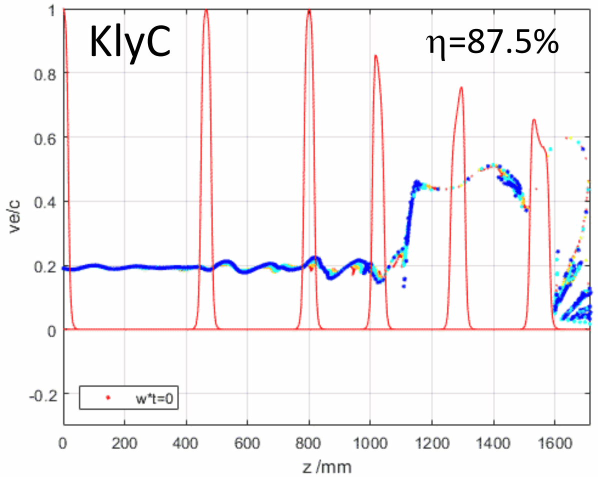
- The first meetings with Thales took place at 11.12.2023(CERN) and 18.01.2024 (Thales).
- It is planned to complete the project and perform the first test in 2026/27.

Particles dynamic in the TS 400 MHz FCC_{ee} MBK at 1MW RF output power.

High Efficiency Klystrons







I. Syratchev, LER WS, CERN, February 2024

CLIC Two-stage MBK klystron: **Pulsed, 1.0 GHz, 24 MW**

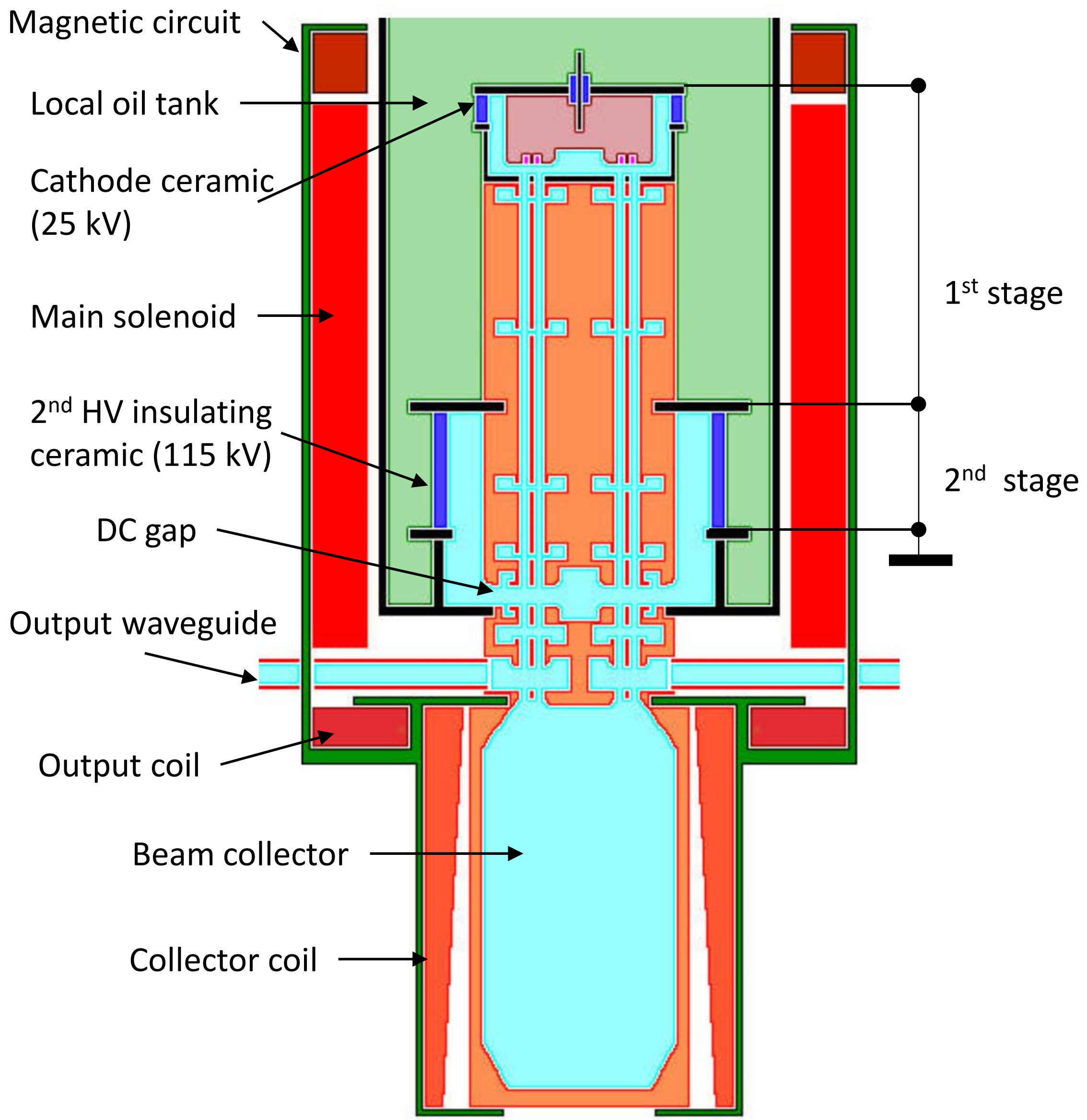
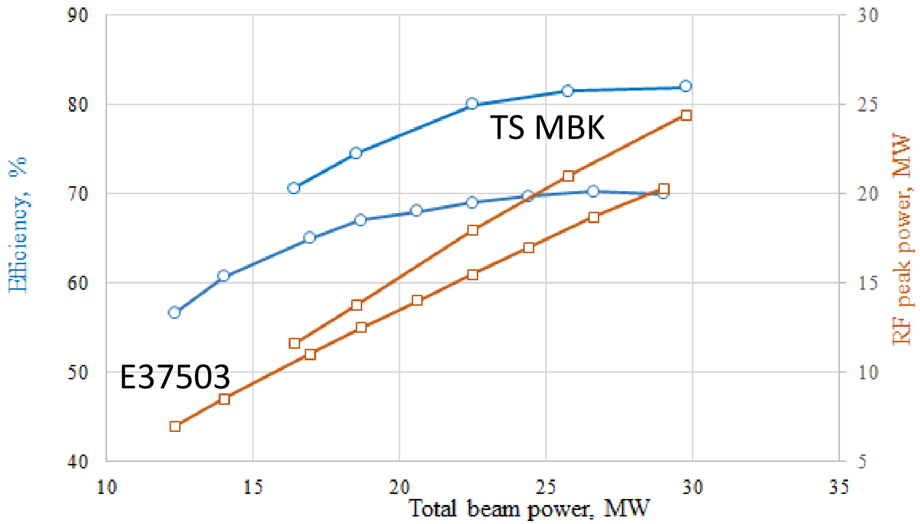


TABLE I. DESIGN AND SIMULATED PARAMETERS (CST/3D) OF THE CLIC TS MBK AND CANON MBK E3750 CATALOGUE DATA

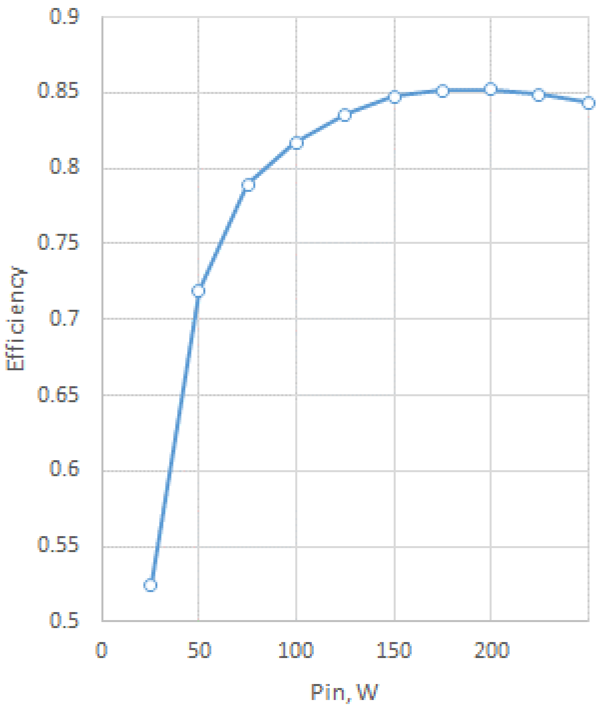
Parameter	TS MBK	E37503	Unit
Operating frequency	1000	1000	MHz
Voltage at the 1st stage	25	160	kV
Voltage at the 2nd stage	140		
Total beam current	212	180	A
Number of beamlets	30	6	
Number of cavities	6	6	
Perveance at the 1st stage	1.77	0.47	$\mu A/V^{3/2}$
Perveance at the 2nd stage	0.133		
Output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

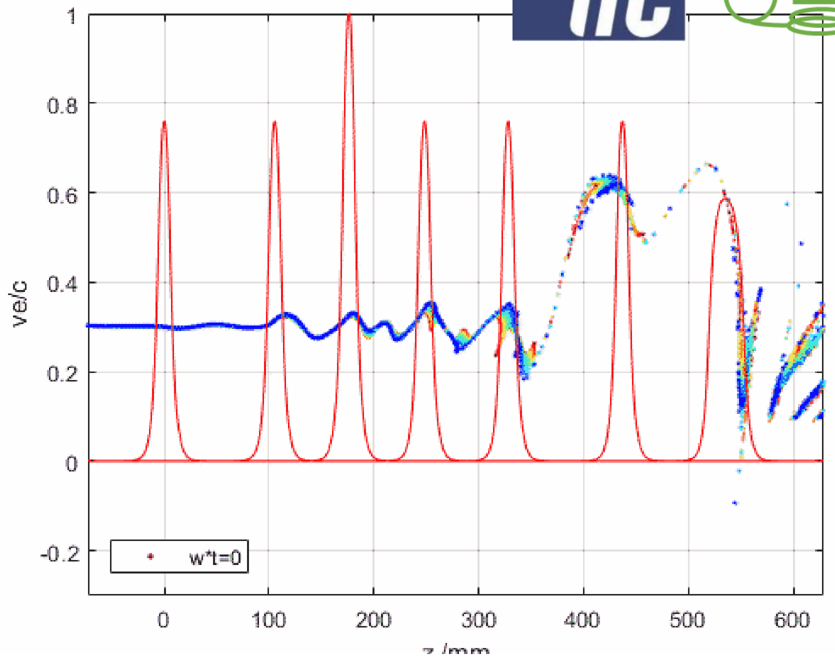


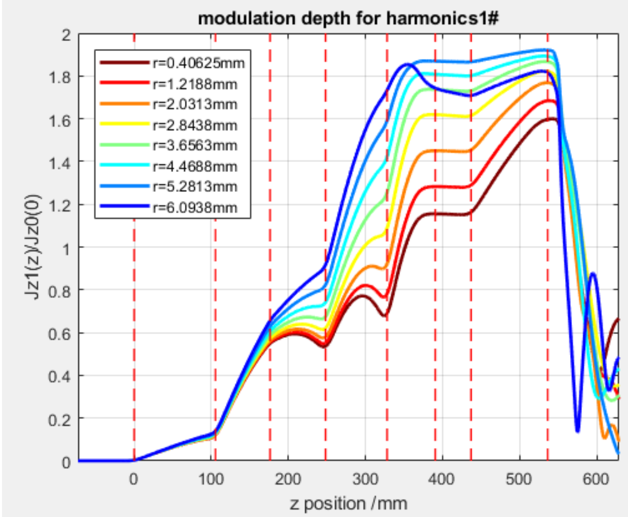
ILC Two-stage MBK klystron: **Pulsed, 1.3 GHz, 10.5 MW**

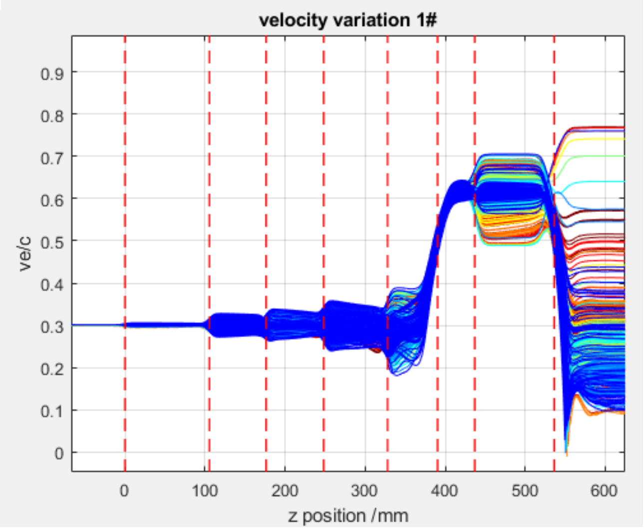
High Efficiency Klystrons

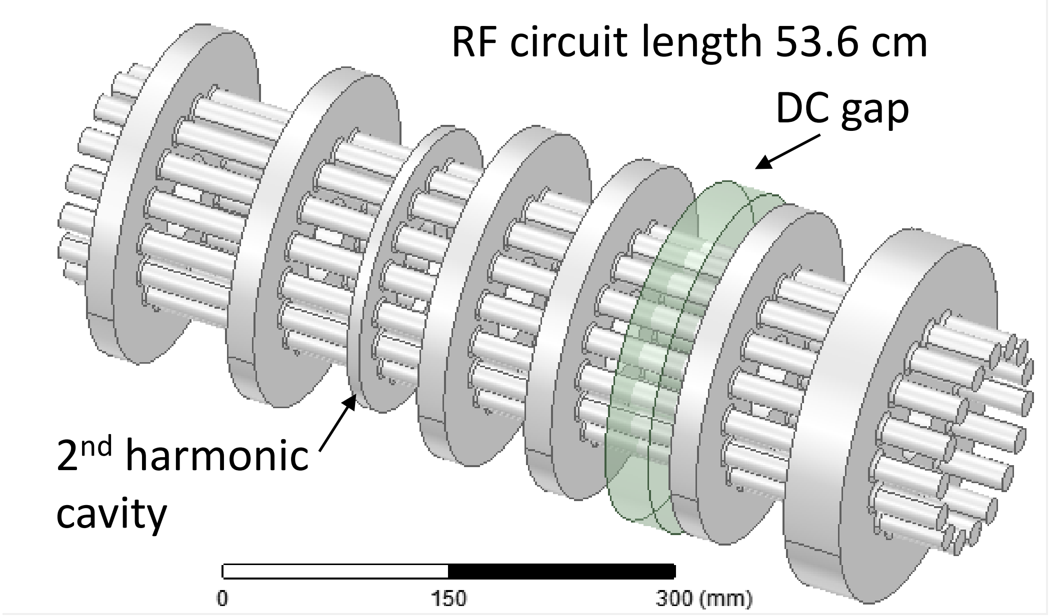
Parameter	TS MBK	E37536	Unit
Operating frequency	1300	1300	MHz
Voltage at the 1st stage	25	118.8	kV
Voltage at the 2nd stage	140		
Total beam current	88	129.5	A
Number of beamlets	16	6	
Number of cavities	7	6	
Perveance at the 1st stage	1.68	0.53	$\mu A/V^{3/2}$
Perveance at the 2nd stage	0.105		
Output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











European Strategy for particle physics. Implementation.
RF Coordination panel (reporting to LDG).

WG5. **RF power sources and High efficiency**

https://europeanstrategy.cern/home https://cds.cern.ch/record/2800190?ln=en

2023->2025

RF COORDINATION PANEL WORKING GROUPS

Coordination: G. Bisoffi (INFN-I), P. McIntosh (STFC-UK) ⟶ Snowmass, Asia, ...

WG1 - Bulk Nb
- **M. Baylac (CNRS-F)** ⟶ *ERL*
- C. Madec (CEA-F)
- L. Monaco (INFN-I)

WG2 - Thin Film SRF
- Claire Antoine (CEA-F)
- Oleg Malyshev (STFC-UK)

WG3 - Couplers (FPC and HOM)
- **Frank Gerick (CERN)**
- E. Montesinos (CERN)
- Axel Neumann (HZB-D) ⟶ *ERL*

WG4 - NC Very High Gradient
- **Walter Wuensch (CERN)**
- David Alesini (INFN-I)

WG5 - RF Power Sources and High Efficiency
- Igor Syratchev (CERN-CH)
- **Graeme Burt (U Lancaster-UK)** ⟶ MC
- Morten Jensen (ESS-Swe)

WG6 - LLRF, AI and ML
- Wojciech Cichalewski (Uni-Lodz, Po)
- Roger Kalt (PSI) - tbc

Underlined: WG chair; **Bold**: national contact to funding agencies; in dark red: external links

WG5 roles/objectives

- To support and to promote development/prototyping of the high efficiency RF power sources for the future **large-scale particle accelerators in Europe**. **LHC** and **FCC_{ee}** are primarily objectives identified for such a development.
- To support accelerators user community in **their needs for high efficiency RF sources** as a synergy with development stated in bullet#1, or as a specialized activity(ies) targeted for the novel (or customized) efficient devices development.
- To support and **to intensify collaboration with industry** to ensure the long-term industrial support for decades to come.

Workshop on efficient RF sources

4–6 Jul 2022
Chateau de Bossey
Europe/Zurich timezone

Enter your search term

- Overview
- Timetable
- Registration
- Payment information
- Contribution List
- Participant List
- Venue
  - Travel to venue
- Accommodation
- Social Event

Following a series of successful workshops on the initiative of the EUCARD and ARIES EU-funded programs, we would like to announce the next Workshop on Efficient RF sources to be held in Chateau de Bossey (Geneva, Switzerland) on the 4-5-6 July 2022. The workshop is part of the I.FAST initiative for **"Sustainable concepts and technologies"**

The workshop is aimed at displaying the recent advances on energy efficient technology for RF sources mainly used in accelerators. As in previous events, we expect a number of experts from public and private sector to participate in the meeting and the discussions around the efficiency of klystrons, IOTS, Solid state amplifiers and RF systems in general.

Organizing Committee Chairs: Nuria Catalan Lasheras (CERN), Mike Seidel (PSI)

Scientific Committee Chair: Igor Syratchev

Processing of Personal Data at CERN: OC11

- Open forum for Labs, Industry and Users.
- 36 participants; 30 talks in 2.5 days.
  (from Europe, USA, Japan and China)

https://indico.cern.ch/event/1138197/

Next HE RF workshop will take place in September-October 2024 (in Spain).