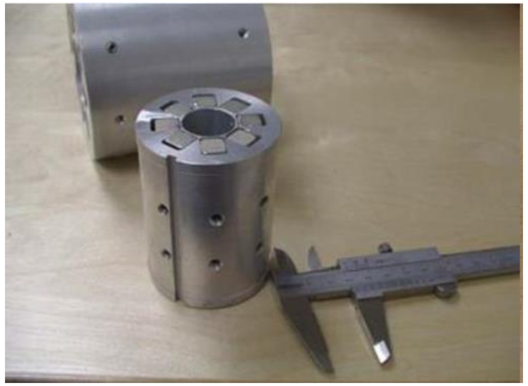
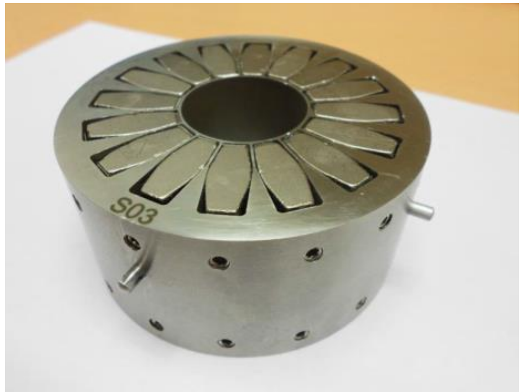
Permanent Magnet for High Efficiency Klystrons
PM4HEK

Nuria Catalan Lasheras – IFAST 2nd Annual meeting. April 2023

Team and background

- CERN Team: led by Dr. I. Syratchev.
  - working for the last 8 years on the development of the tools and techniques to improve efficiency of klystrons for accelerators
  - One tube built by CANON ETD (Japan) has achieved an efficiency of 54% from an original 43% design.
  - A new tube is under construction in Thales as part of the IFAST 11.2 work package.
- ELYTT team: Led by J. Lucas.
  - Ample experience in permanent magnets and (EM) solenoids for klystrons.

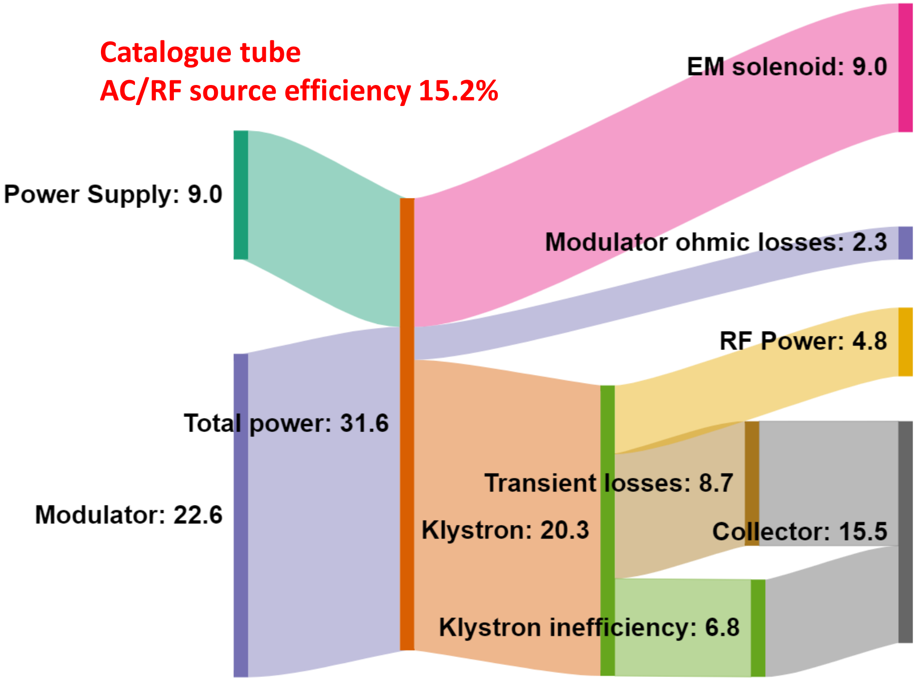




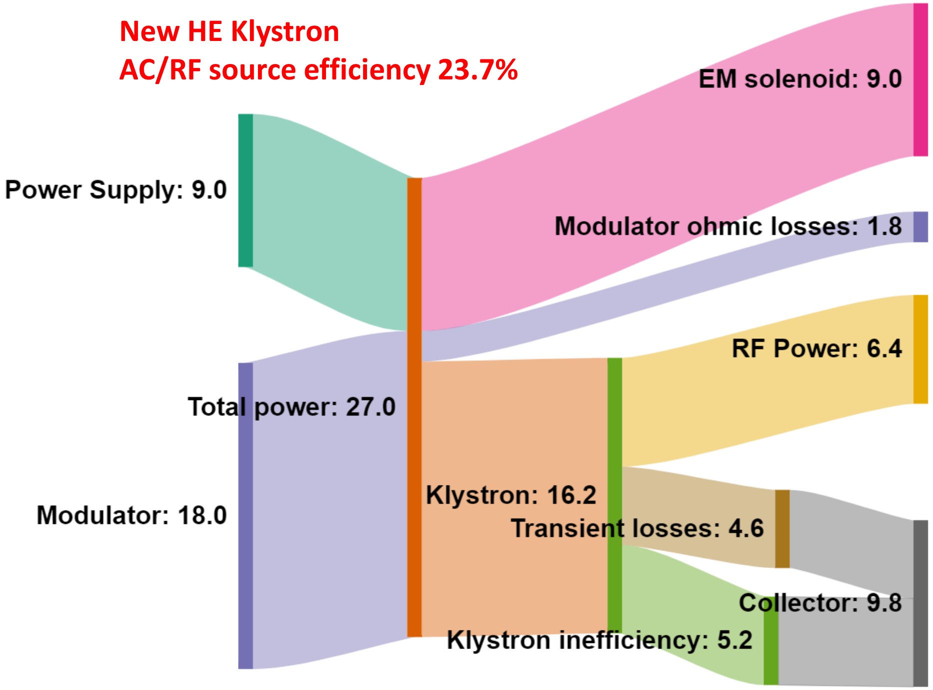
Technical scope

- Klystrons use an electromagnetic solenoid to guide the electrons on a vacuum tube.
- Electrical and cooling energy required represents a large fraction of the total power, especially in low duty cycle, pulsed systems.
- The contribution of the magnet is only enhanced when designing and building high efficiency klystrons and modulators 28% to 32%
- We want to design and build a permanent magnet solenoid for an available HE klystron
- The final product will reduce the operational costs of any accelerator together with the associated carbon footprint.

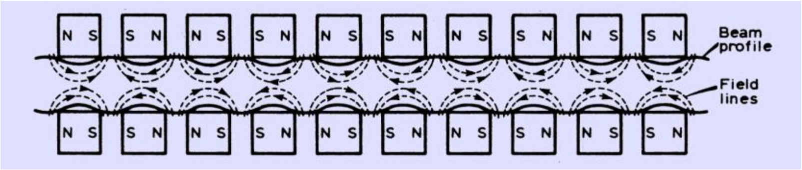
Catalogue tube
AC/RF source efficiency 15.2%



New HE Klystron
AC/RF source efficiency 23.7%



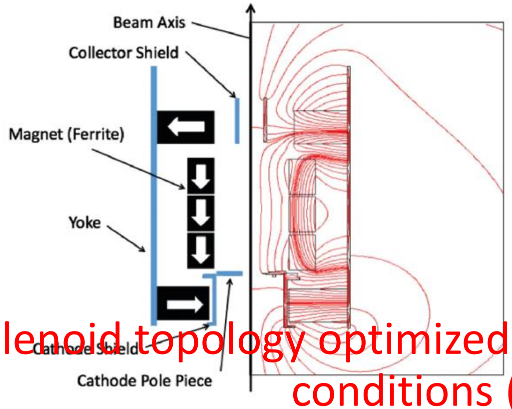
State of the art

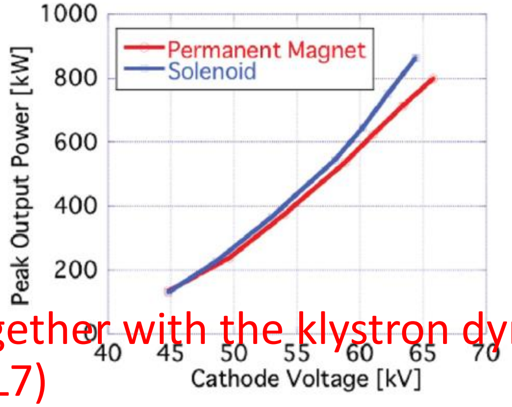


- Periodic permanent magnet (PPM) configuration consists of alternating polarity rings set around the RF cavities

- This topology produces an oscillating envelope for the electron beam and generate losses along the tube.
- High efficiency klystrons require a much tighter control of the beam

- Already demonstrated PM pure solenoid by KEK/CANON (TRL6) with some loss of performance



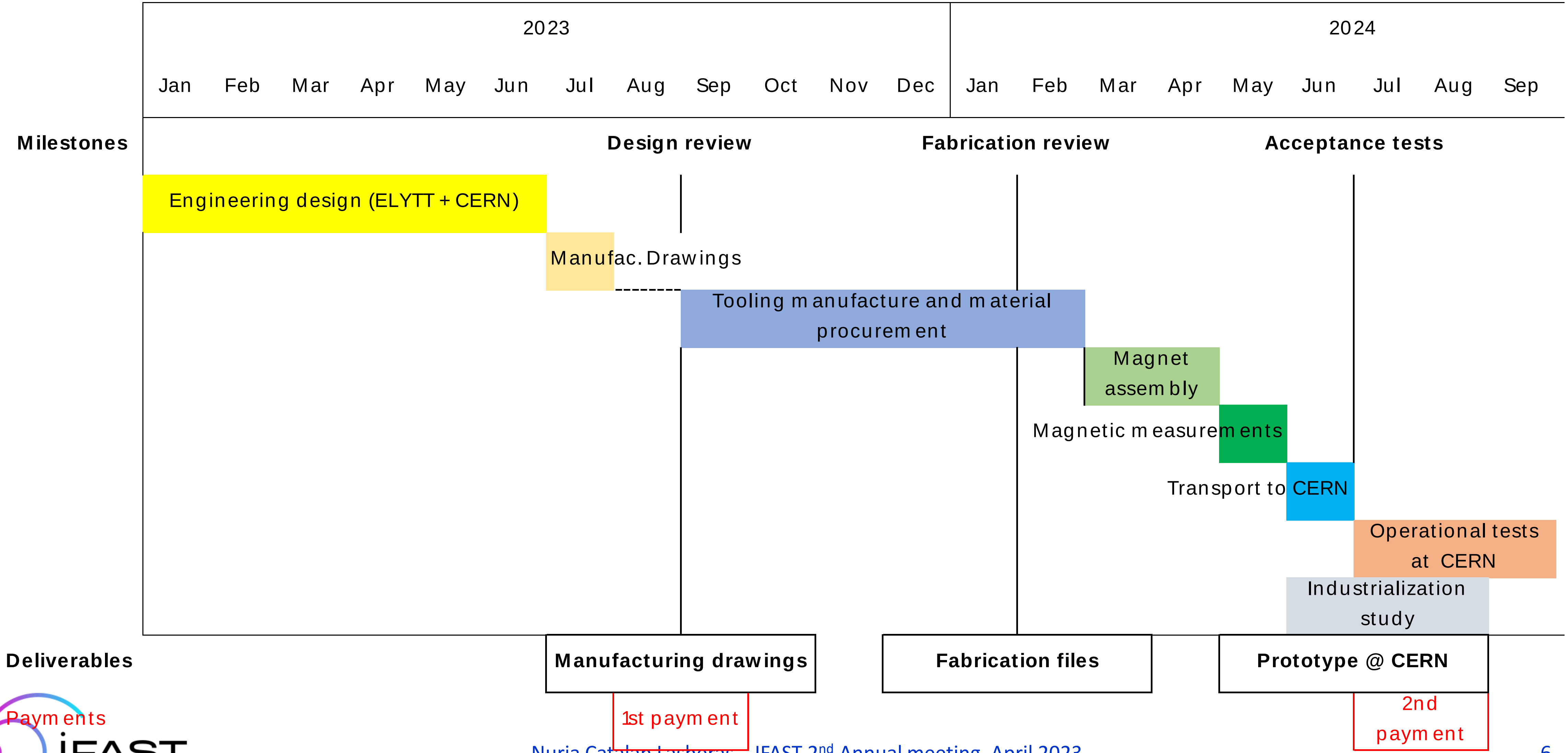


We propose to use a pure solenoid topology optimized together with the klystron dynamics in operation conditions (TRL7)

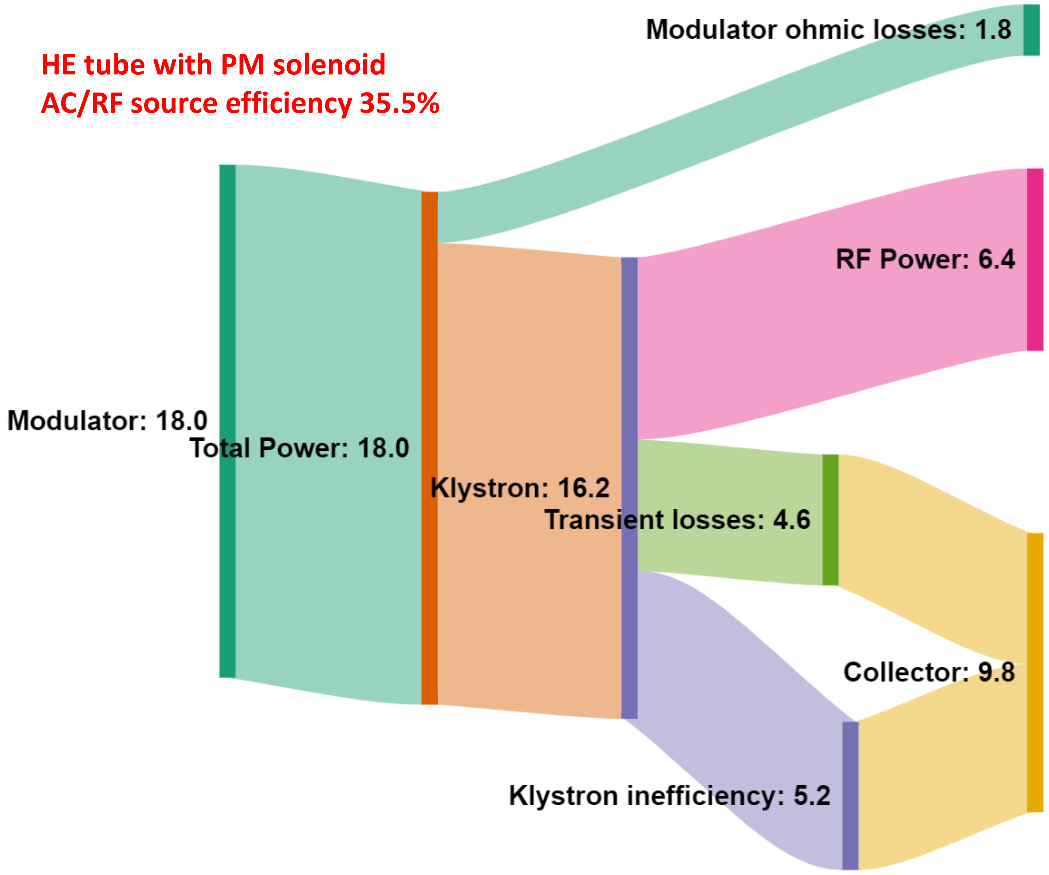
Work plan and resources

Work package	Partner in charge	Description	Resources
WP1: Magnet specification	CERN	Definition of magnetic field profile, mechanical envelope. Setting up of the verification process	CERN: Fellow and supervision covered by CERN funding 4 PM
WP2: Design of the PM solenoid	ELYTT	Design of the magnetic channel, verifications in klystron simulations. Manufacturing drawings.	ELYTT: design team 3 PM CERN: Fellow and supervision covered by CERN funding 4 PM
WP3: Magnet fabrication	ELYTT	Procurement of tooling and materials. Manufacturing. Assembly	ELYTT: production team 6PM. Material 15 K CERN: Travel 10K
WP4: Magnet tests	CERN	Magnetic tests in stand alone magnet. Insertion in the klystron and RF test	ELYTT: design and production team 1PM CERN: travel 5 K
WP5: Industrialization	ELYTT	Cost optimization, Industrialization model, ISO standardization	ELYTT: commercial team 1 PM

Work schedule



Final product



- From 15.2% to 23.7% to 35.5% efficiency in the global RF system
  - reduces the electricity bill,
  - reduces capital investment (no power supplies, no cooling of solenoid),
  - have a smaller footprint (embarked solutions like cargo scanners, X-rays…)

- Commercialization, scalability, industrialization and manufacturability will be studied as part of the project

Applications and Impact

- Klystrons are used for communications, defense, industry, medical, radar, and scientific applications. Their use in accelerators represents only a small fraction of the current market.

- The solenoid currently used by CANON fits two different klystrons used for science, industry and radar.

- After validation of the prototype in operational conditions, the technology can be transferred to a large fraction of products already available (short channel and high frequency).

- Similar products also commercialized by CPI and THALES

Image	Type	Klystron	Coil Current (A)	Coil Voltage (V)	Cooling	Coil Weight (kg)	Coil L × Φ (m)	Oil Tank (kg)	Oil Tank W × D × H (m)	Down load
For CW / Long pulsed klystron										
–	VT-68960B	E37504	15/15/15	300/300/300	L	450	1.6×0.6	–	–	–
–	E3766A_ACC	E3766A	20/20	20/470	L	1,100	1.4×0.9	550	1.5×1.5×1.0	–
–	VT-68933B	E3766A	20/20	20/470	L	1,100	1.4×0.9	–	–	–
–	VT-68958	E37503	50/50/50	10/150/25	L	3,100	2.1×0.9	–	–	–
–	VT-68945	E37701	8.2	450	L	900	1.1×0.9	–	–	–
–	VT-68950	E37501	24	100	L	280	0.6×0.5	–	–	–
–	VT-68948	E37750	25	100	L	520	0.6×0.6	–	–	–
–	E37750_ACC	E37750	25	100	L	520	0.6×0.6	430	1.0×1.3×1.3	–
–	VT-68927B	E3739B	33	30	L	120	0.4×0.3	–	–	–
For pulsed klystron										
–	VT-68946	E37612	18	250	L	835	1.2×0.5	–	–	–
–	VT-68934,E/ (VT-68934,G)	E3772 E3779,B E3783 E3765,A E3735A E37325 E37326	42/32	160/5	L	400	0.6×0.5	–	–	–
–	VT-68934,F	E37307	42/32	160/5	L	400	0.6×0.5	–	–	–
–	VT-68931A	E3730A E3754 E37300 E37302 E37308 E37310	20	250	L	520	0.7×0.5	–	–	–
–	VT-68922	E3730A E3754 E37300 E37302 E37308 E37310	25/38/19 24/17/10	15/30/25 40/23/10	L	520	0.7×0.5	–	–	–
–	VT-68915	E3712 E3729 E37320	24	250	L	1,000	1.1×0.6	–	–	–
–	VT-68953	E37314,A E37333	24	250	L	1,400	1.1×0.6	–	–	–
–	VT-68924A	E3734 E37201	22	100	FA	135	0.3×0.5	–	–	–
–	VT-68926B	E37202	30	250	L	850	0.7×0.6	–	–	–
–	VT-68954	E37210 E37212	30	260/280	L	1,000/1,460	0.7×0.7	–	–	–
–	VT-68956	E37113 E37115	34/30	200/20	L	420	0.3×0.7	–	–	–
–	VT-68970	E37116	27	233	L	800	0.4×0.8	–	–	–

https://etd.canon/en/product/category/microwave/klystron.html

Thanks!