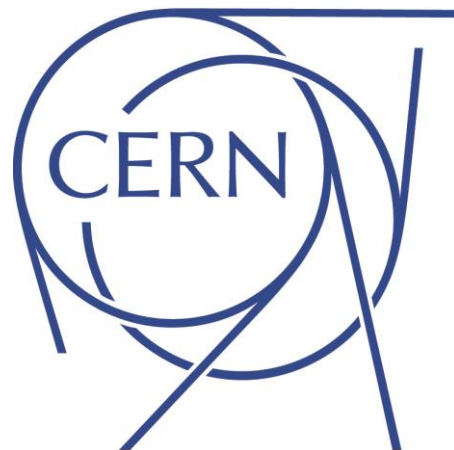


## WP 11.2 High Efficiency Klystron Prototype

Nuria Catalan Lasheras – IFAST 2<sup>nd</sup> Annual meeting. April 2023



**THALES**

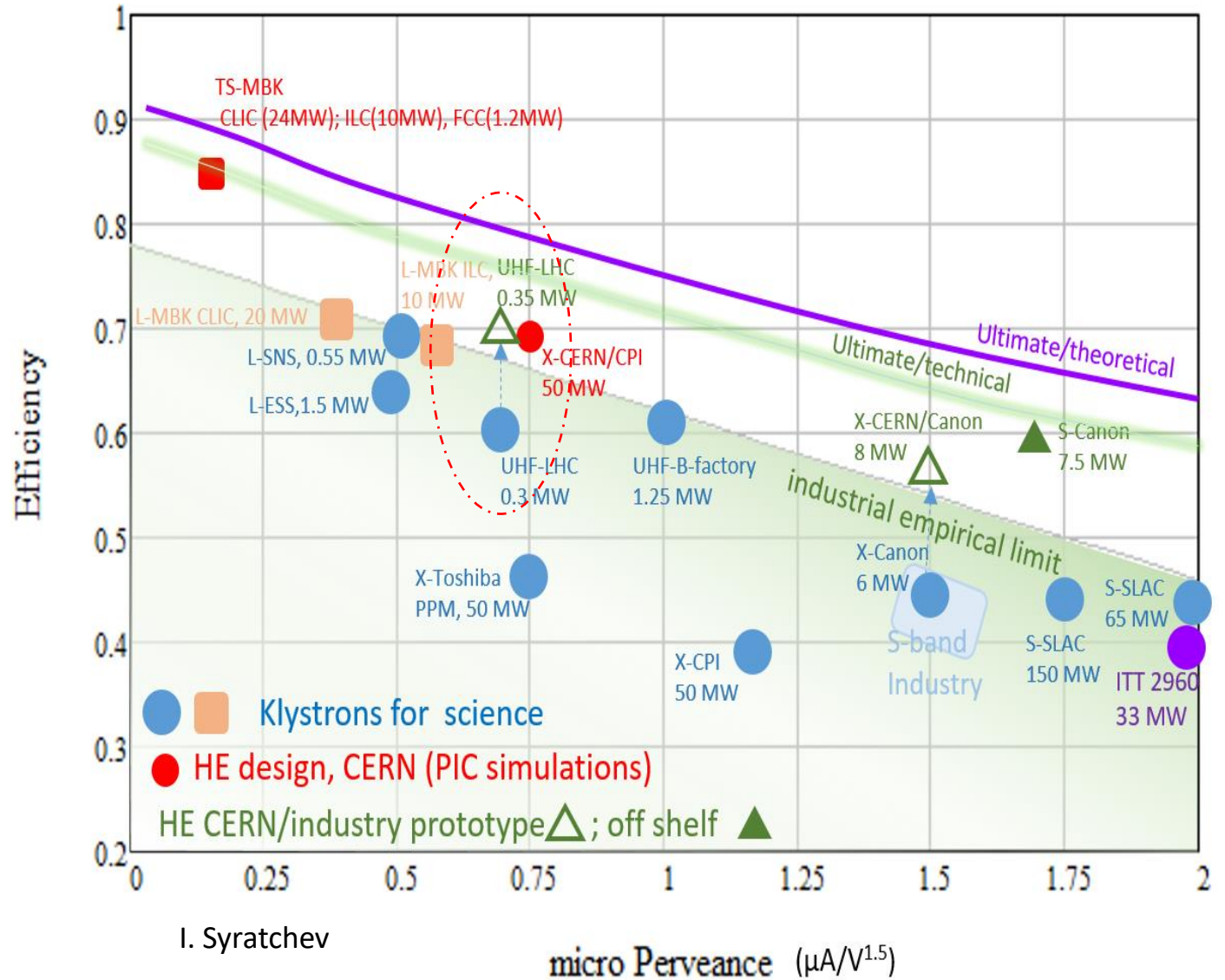
# High efficiency klystrons?

Klystrons in the market limited by an empirical dependence to perveance

Major CERN involvement on higher efficiency klystrons since 2017 led by I. Syratchev

New design rules for higher efficiency validated by powerful simulations (KLYC)

Industrial prototypes are being manufactured around the world



I. Syratchev

# Current LHC klystrons

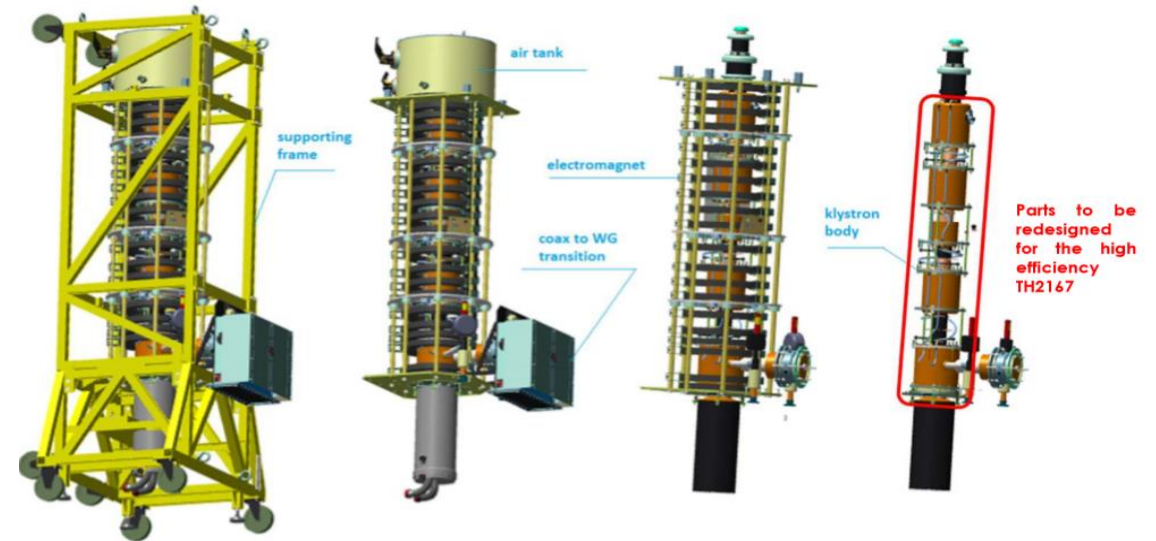
- Total 16 THALES TH2167 klystrons
  - 300kW, CW saturated output power at 58kV 8.4A (62% efficiency)
  - Presently operated at ~220kW (-1.5dB below saturation)
- High Luminosity LHC upgrade will require more RF power
- At least 350 kW saturated output RF power per klystron (the exact value is not yet 100% confirmed)
- At an operating point compatible with the existing power supplies ( ~58 kV x 9A)
- Need to increase the klystron efficiency to 67% min.

*From A. Beunas FCC week 2019*



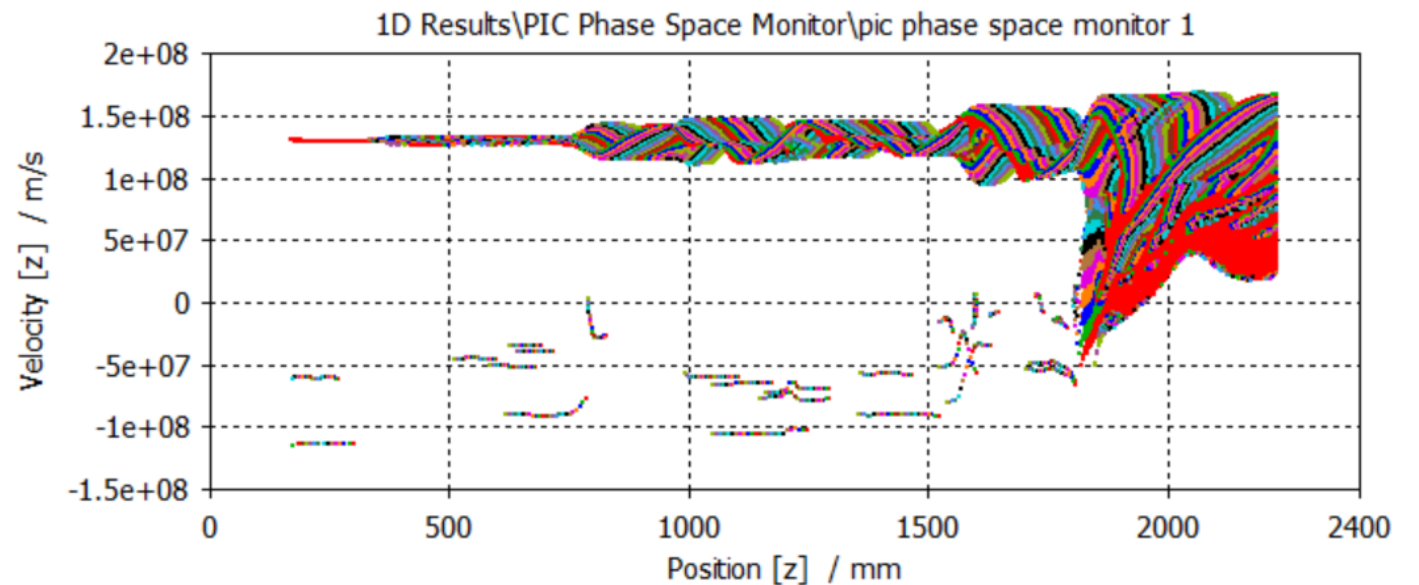
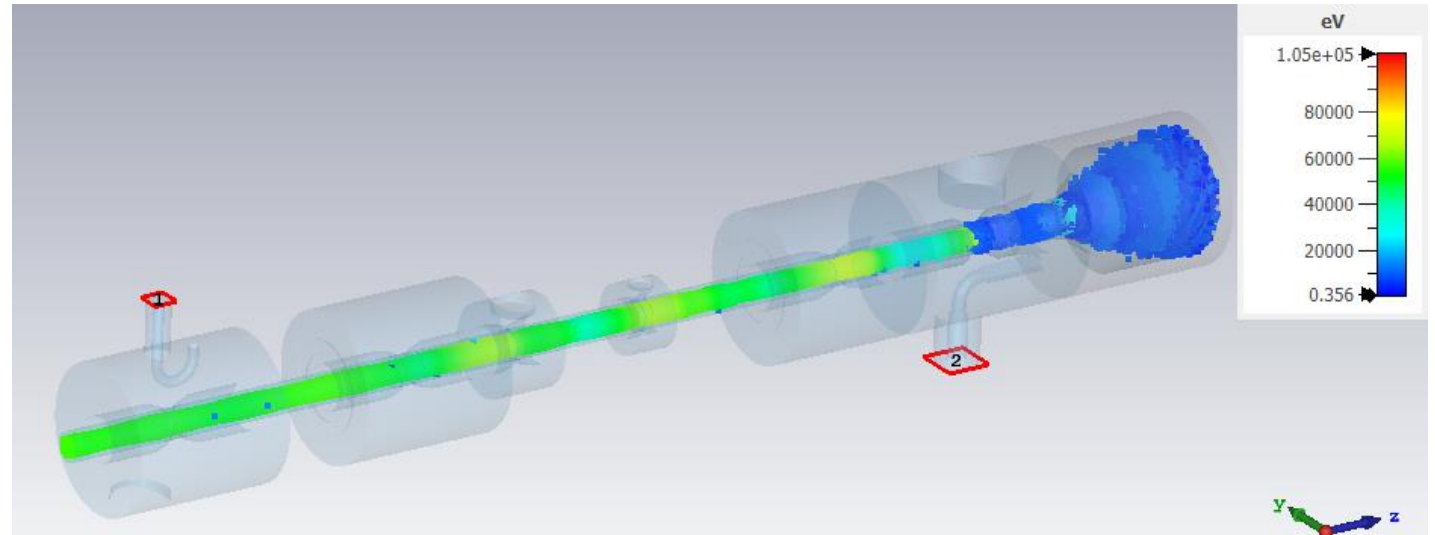
# Objective of I.FAST WP 11.2

- Design and build an industrial prototype of the LHC klystron reaching 70% efficiency, in collaboration with THALES.
- In order to control the costs, the choice was made to retrofit the existing LHC klystrons, TH2167, with the aim of reusing some components (e.g. solenoid).
- Kick off meeting on Sept 2021

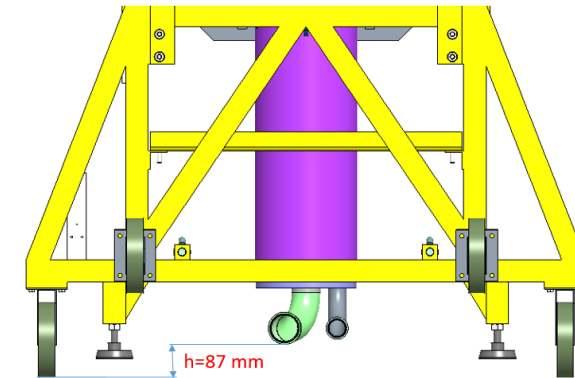
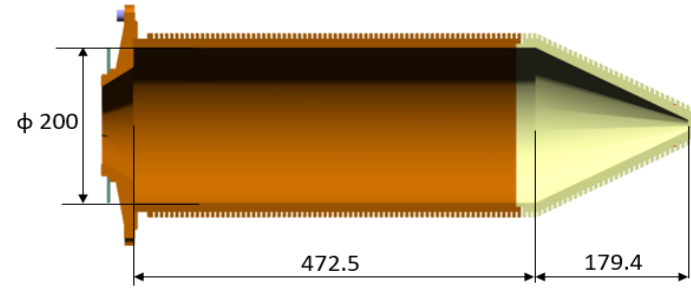
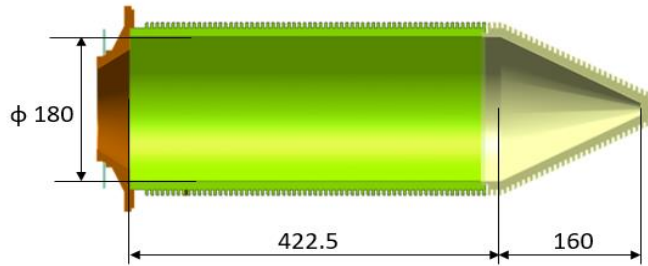


## Design and simulations

- Twelve months effort by CERN and THALES teams.
- Final design converged end 2022
  - Saturation at 70 W,
  - Voltage 57.7 kV
  - beam current 9A
  - reduced magnetic field on last two coils
- RF Efficiency = 69.84%
- PIC simulations verified by THALES

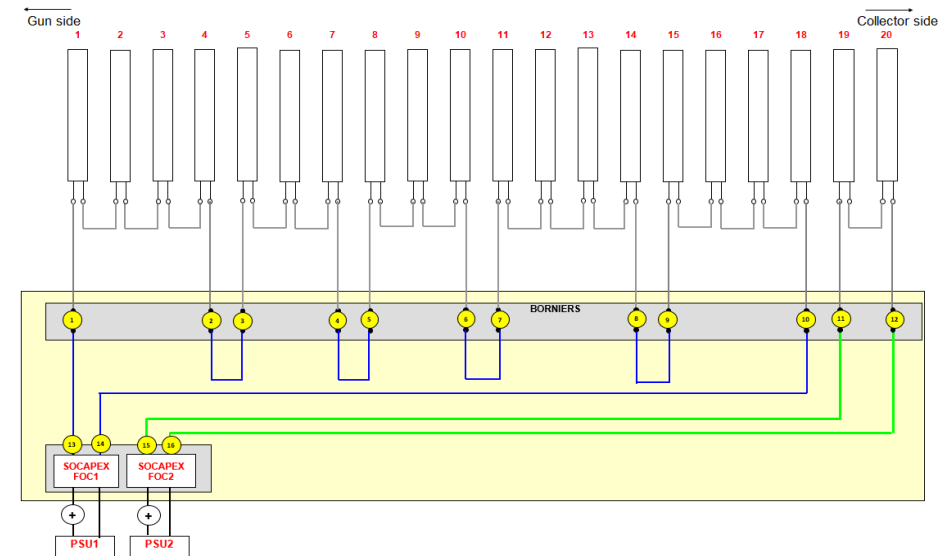


# Required modifications



(On the TH2167 h=156mm)

- Larger collector to optimize heat deposition
- Supporting frame to be modified
- Solenoid coils powered independently by two power supplies



# Preliminary design review held in Oct 2022

High level 3D step file delivered to Thales on July 2022

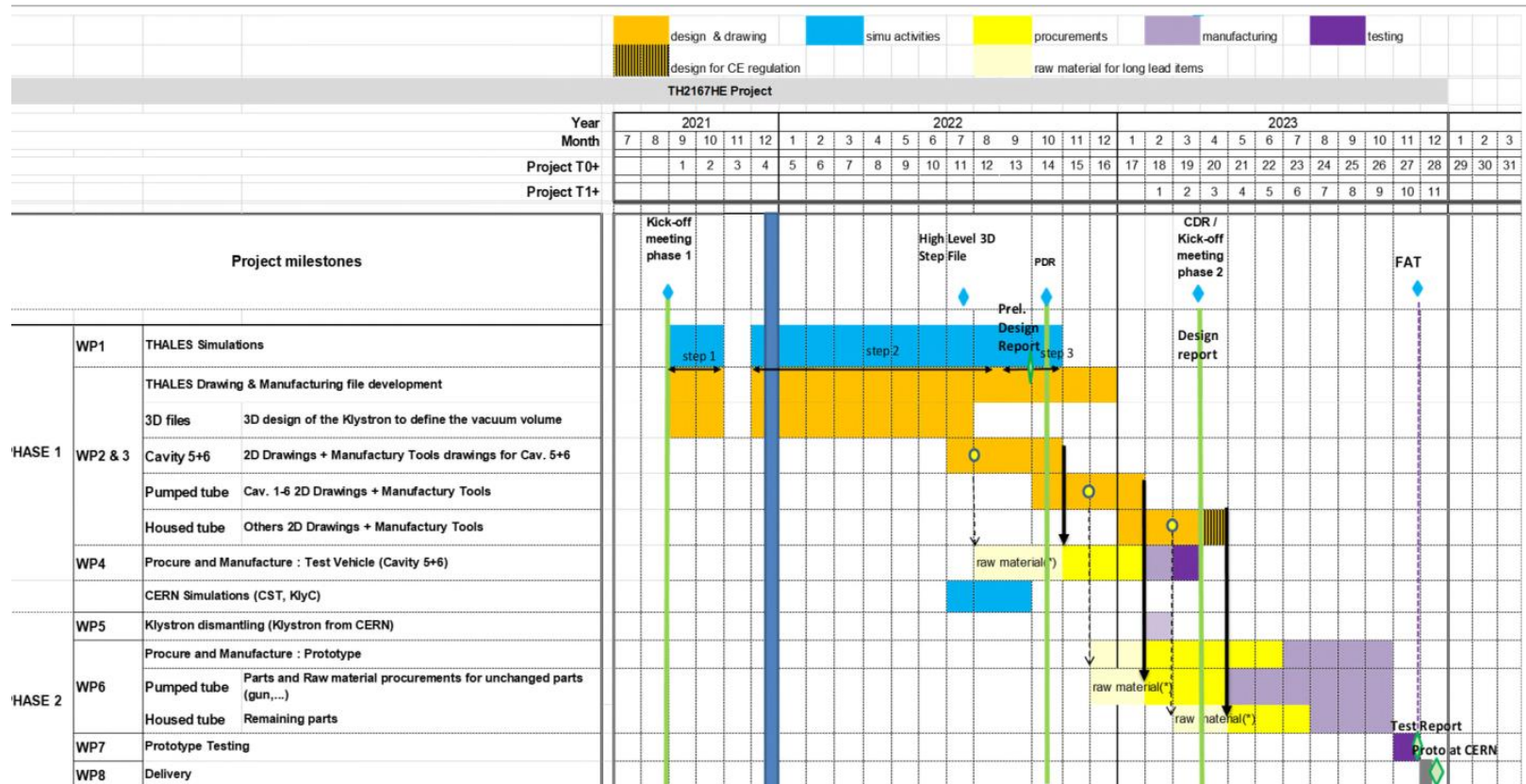
Preliminary design review October 2022

Additional drawings foreseen

Test vehicle measurements before final critical design report (CDR)

Procurement of long lead raw material launched

Expected delivery end of 2023



# Progress report from Thales (March)

- Test Vehicle progress :
  - Raw material for parts of cavity 5 and 6 are now available (after some major difficulties due to material shortage – forged copper),
  - Parts' drawings for cavity 5 and 6 are validated
  - Orders for machining these parts are placed,
  - Manufacturing of the Test Vehicle next
- Prototype progress :
  - Manufacturing of unchanged parts (same definition than TH2167) are integrated in production line.
  - Priority given to (new) collector sub-assembly. Drawings are now validated
  - Orders for these parts are now placed.





# Additional delays since last update

- Detailed drawings for Cavities 5 & 6 (parts drawings) took 3 months longer than expected.
  - Change of process from spinning to tube section assembly due to availability of subcontractors
  - Still some drawings for the tube assembly pending
- Test vehicle parts and assembly (+ 4 months)
  - Raw material procurement delay
  - Specialised work and experts availability as opposed to “mass production”
- Expected FAT in March 2014 and delivery to CERN April 2024



# On CERN side

- Monthly meetings with Thales
- Klystron 001 being stripped from auxiliary systems to be sent to THALES for up-conversion
- High Voltage testing station building 112 being refurbished in 2023
- Verification of rating for circulators, loads and directional couplers in the test bench
- Increase power from the current LHC system
  - Understand losses on the lines by re-calibrating power measurements
  - Re-match circulators dynamically
  - Study additional working points to improve efficiency at low power

# Conclusions

- Lots of work done. Design work and drawings almost finished
- Manufacturing started for standard pieces and test vehicle.
- Critical design report after the vehicle tests report
  - cavities may still need some re-design and remanufacturing.
  - Raw material already available
- Large delay accumulated and current plan just meets IFAST delivery date but not acceptance test
- Test bench at CERN getting ready for validation tests
- Validation also needed for HL-LHC project to evaluate prospects of upgrading all LHC klystrons

Thanks!



# Exploring efficiency at low power

