Karlsruhe Institute of Technology

Commissioning of the Gyrotron Test Facility FULGOR First Results

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Content

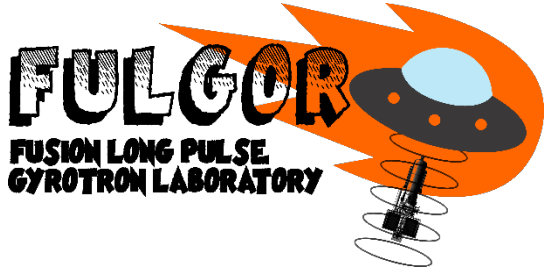
- Introduction
- Requirements on FULGOR
- Main components of the teststand
- Commissioning and first experimental results
- Conclusions

Background

- Fusion Long-Pulse Gyrotron Laboratory – FULGOR
- First Application of project: 2009
- Approval of Project: 2013

- General Goal:

  Center for development and testing of high-power gyrotrons for present and future application in magnetically confined plasma

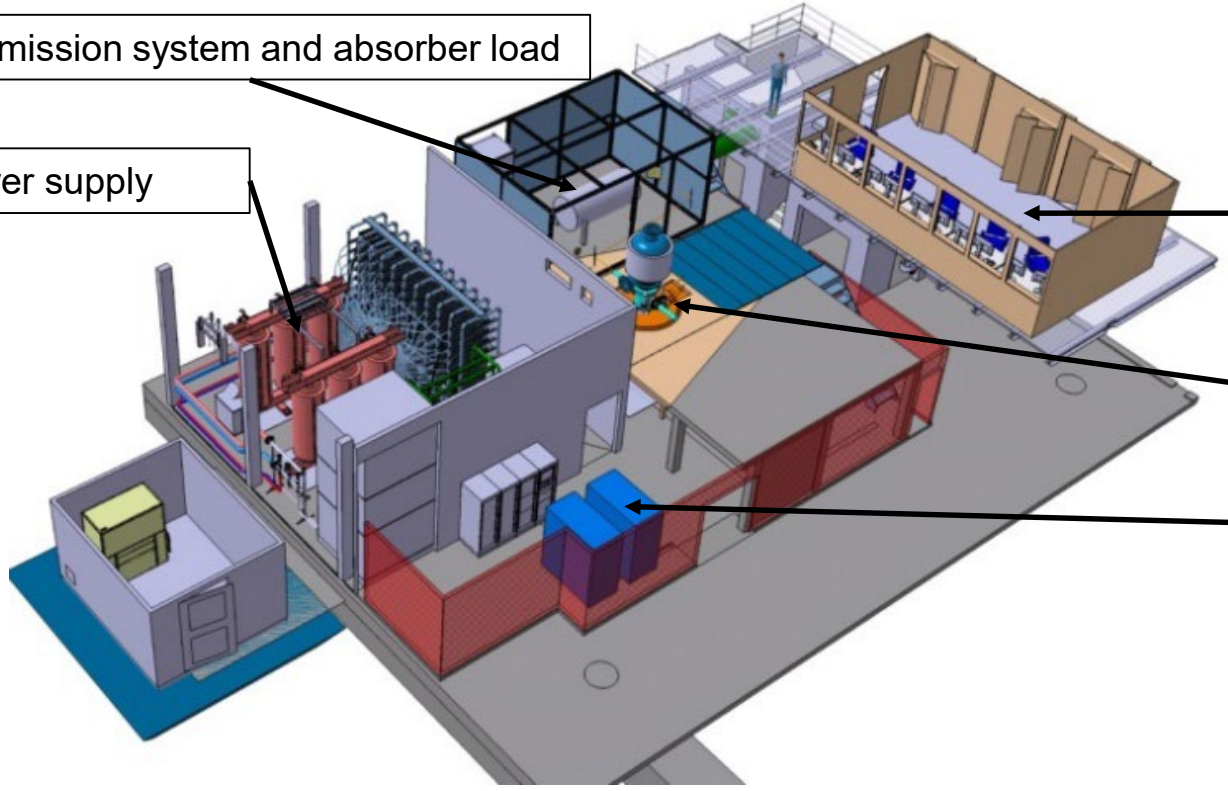


Main Requirements on FULGOR

Electrical input power	10 MW
Long pulse operation	Up to 3600 s
Operating frequency	Up to 240 GHz
RF power	Up to 4 MW
Cooling system	For full power operation in CW
Flexible system for the next decades of gyrotron development	
Output voltage	Up to 130 kV
Beam current	Up to 120 A
Gyrotron efficiency	> 60 % (MSDC)
Advanced control system, data acqusition and safety system	

More on MSDC?
See: Poster 2-17, B. Ell: *Progress in the Short-Pulse E×B Drift Two-Stage Depressed Collector Prototype for Gyrotrons*

Overview of FULGOR

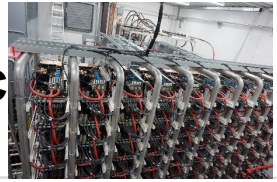


High Voltage Power Supply

High Voltage DC Power Supply (HVDCPS)

Output Voltage	≤ 90 kV
Output current	≤ 120 A
Pulse length	≤ 3600 s
Maximum output voltage ripple	≤ 500 V_{P-P}
Max. energy deposition into arc	≤ 10 J
Rise time (10% - 90%)	50 µs
Modulation	≤ 5 kHz

EPSM Technology allows several **DC taps for MSDC**



High Voltage Pulsed Power Supply (PPS)

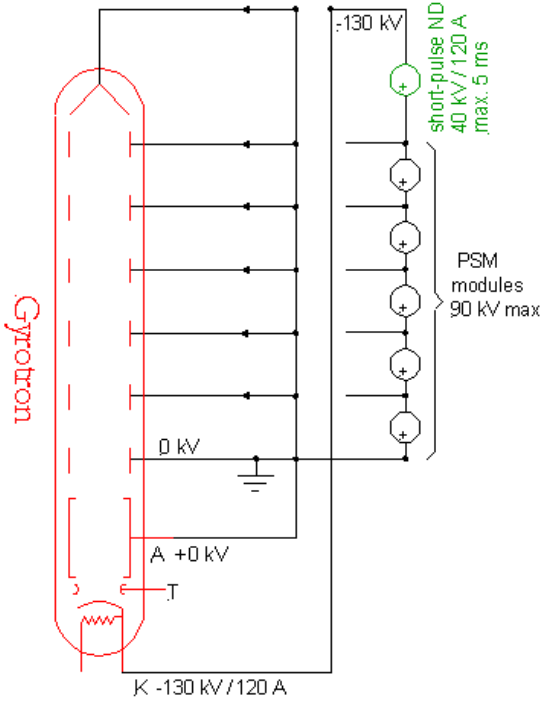
Output Voltage	≤ 40 kV
Output current	≤ 120 A
Pulse length	≤ 5 ms
Max. energy deposition into arc	≤ 10 J

- PSM Technology
- Average power: 12 kW
- In total with HVDCPS: 130 kV

AMPEGON

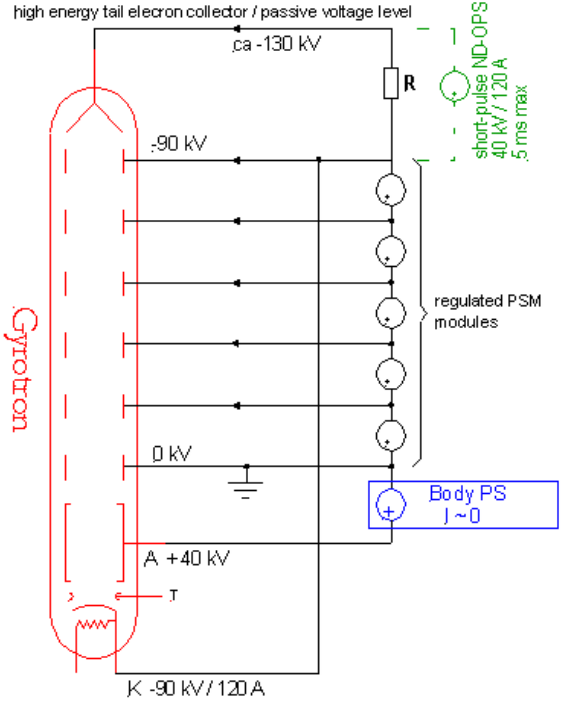
Operation Modi

Short pulse operation with PPS (5 ms)



A) Non-depressed: 130 kV / 120 A / 5 ms

Long pulse operation without PPS but with BPS



B) Depressed: 90 kV / 120 A / CW

Body Power Supply

- Body Power Supply

Output Voltage	≤ 50 kV
Output current	≤ 100 mA
Pulse length	≤ 3600 s
Maximum output voltage ripple	≤ 500 V_{P-P}
Max. energy deposition into arc	≤ 10 J
Rise time (10% - 90%)	≤ 100 µs
Modulation (ΔU 20 kV)[1] Modulation (ΔU 30 kV)[1] [1] (Modulation endurance ≥ 40 s)	≤ 5 kHz ≤ 1 kHz

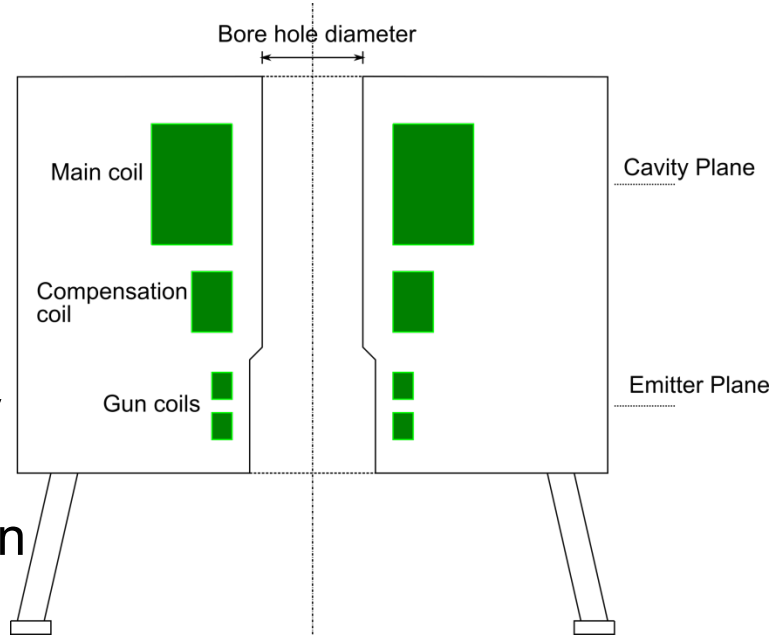
Some results from Site Acceptance Tests

High Voltage Power Supply	
Load	Ohmic
Rise / switch off time (9 kV – 81 kV)	38 µs (several ms adjustable)
Overshoot (90 kV, 120 A)	278 V, ± 0.15 %
Ripple (90 kV, 5-120 A)	108 Vpp, 0.12 %
Modulation	5 kHz, 30 kV
Shortcut rest energie (< 10 J)	Wire test (Cu, 0.015 mm^2)
Similar results including PPS, 130 kV/120 A	

Body Power Supply	
Rise time (9 kV – 81 kV)	80 µs
Overshoot	< ±0.3 %
Ripple	≤ ±0.126 %
Modulation	30 kV/ 1 kHz, 20 kV / 5 kHz for 40 s
Shortcut rest energie (< 10 J)	Wire test (Cu, 0.015 mm^2)

Superconducting Magnet

- Dry Superconducting Magnet
- Bore hole diameter: 240 mm
- Max. magnetic field strength: 10.5 T
- Optional: diple coils to shift e-beam laterally
- 4 independent coils to optimise configuration

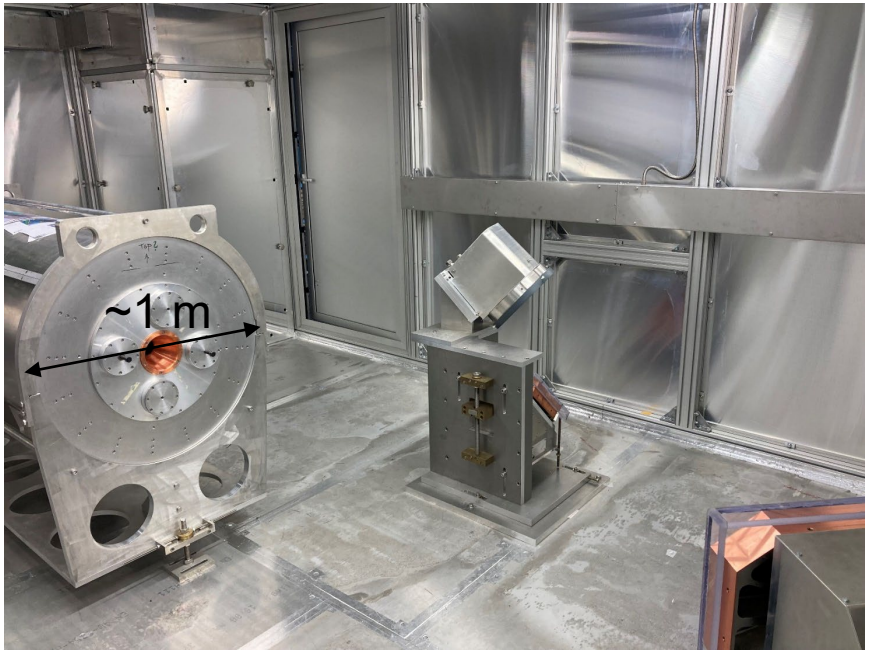


- → under procurement

RF Transmission system and absorber load

- Quasi-optical transmission operated under air
- Broadband design with good transmission properties in the range of 170 …240 GHz
- Water cooled copper mirrors (and polarisers) for CW operation
- 2 MW, CW load with internal teflon pipes for RF absorption in water
- RF entrance diameter: 60 mm, total length ~ 2 m

Designed and manufactured by IGVP, University of Stuttgart

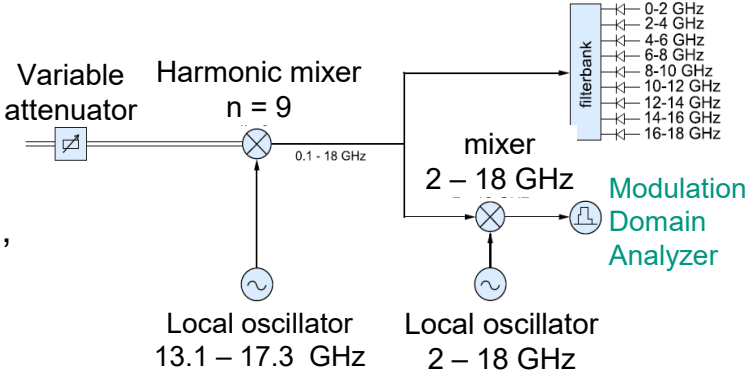


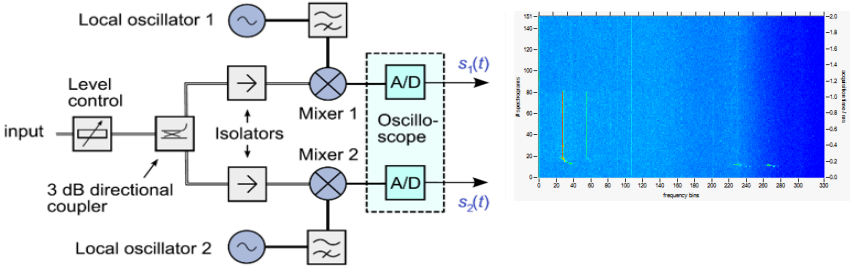
μ-Wave Diagnostics

- Upgrade up to 260 GHz

- Frequency measurement using:
  - Filterbank (Estimation of the frequency, sub-channels of 2 GHz, Detection with wide-band RF diodes, sampling with oscilloscope, 24 dB dynamic range)
  - Modulation domain analyzer (analysis of f vs t, high resolution (< 100 kHz), limited bandwidth, 20 dB dynamic range)

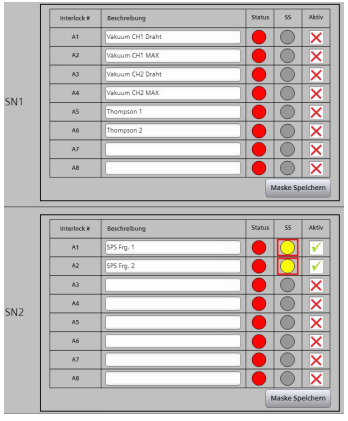
- Upgrade of a Pulse Spectrum Analysis System (PSA) to 260 GHz is planned (dynamic range 60 dB)

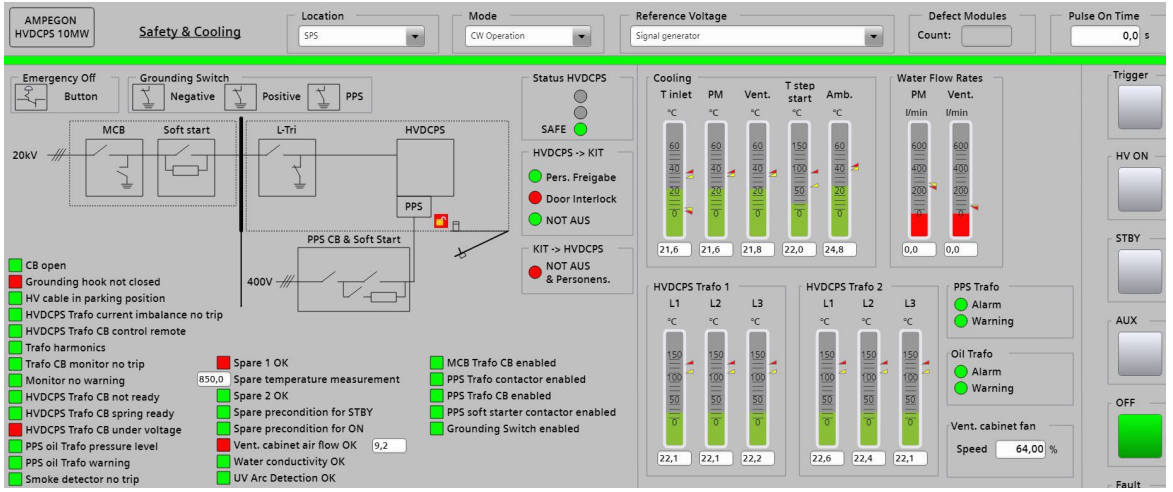




Control system

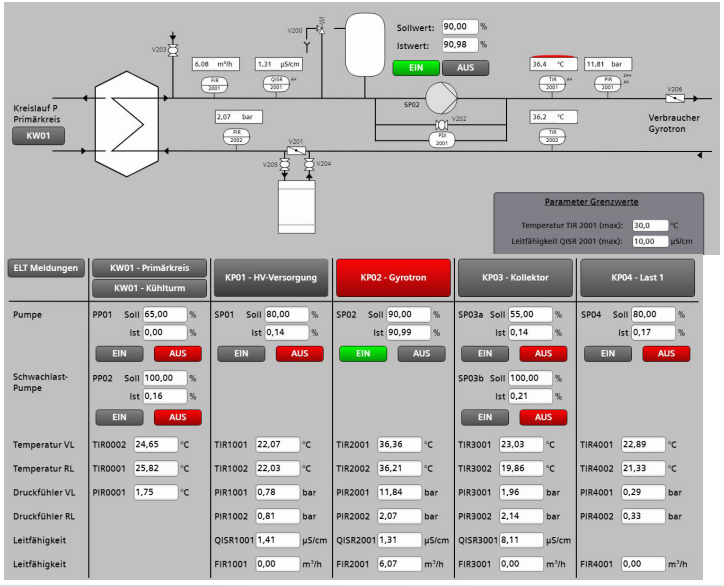
- Control system: SIEMENS TIA V16 with S1500 CPU
- Visualisation: Browser based
- FULGOR Fast Interlock System (FFIS, redundant):
  - 16 Input channels
  - Typ. reaction time 8.5 µs
  - Arc detectors, vakuum, over current



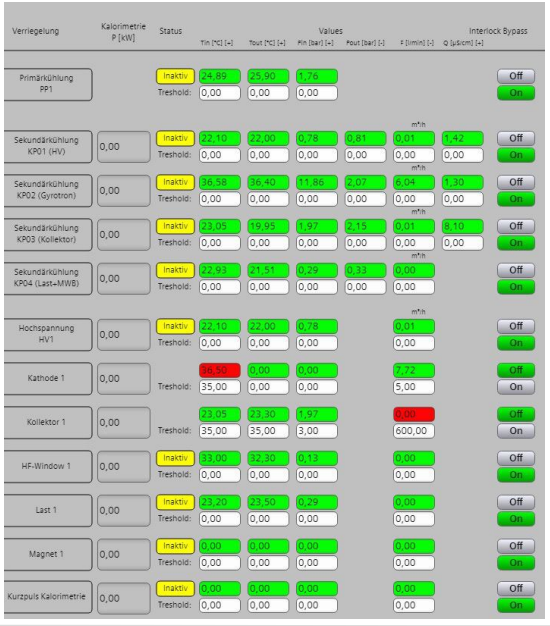


Cooling system

- Control of all cooling channels of the gyrotron and teststand
- Visualisation and overview of cooling channels



- Monitoring of flow rate, pressure, temperature and threshold values
- Interlock signals

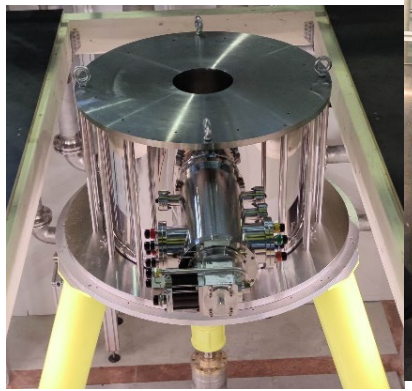


Commissioning and first experimental results

- Installation of new 6 T magnet (Cryomagnetics)
- Installation of a 1.5 MW short pulse gyrotron, 140 GHz
- Pre-prototype W7-X gyrotron with well known performance from previous experiments

(Z. Ioannidis, et.al., *Generation of 1.5MW-140GHz pulses with the modular pre-prototype gyrotron for W7-X*,
IEEE Electron Device Letters, **42**, 6, June 2021,
DOI: 10.1109/LED.2021.3073221)

- Start of operation and verification of teststand and magnet in April 2022



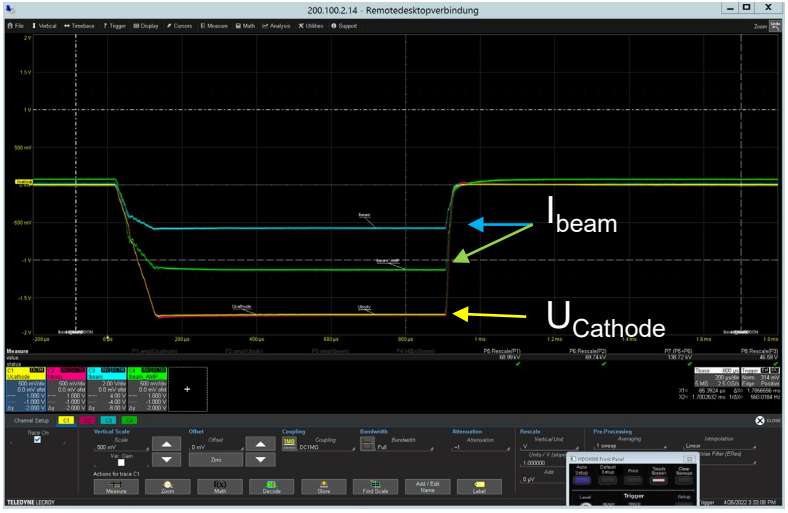
Commissioning and first experimental results

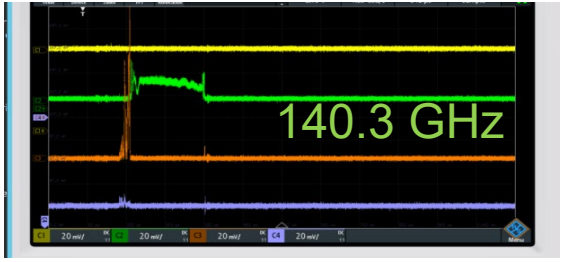
- Operation of the 1.5 MW short pulse gyrotron with nominal parameters (70 – 85 kV, ~ 40 - 55 A)
- Output Power: 500 – 700 kW

- No time consuming optimisation

- Basic operation of gyrotron and magnet was successfully verified

→ Installation of industrial CW gyrotron





Commissioning and first experimental results

- Installation of TH1507U
- Supplier: THALES
- Start of operation: short pulse optimisation

Conclusions

- FULGOR teststand has been constructed during the past year
- All systems have been installed and tested
  (exception: nominal magnet)
- First tests with a short pulse gyrotron have been performed successfully
- Tests with industrial CW gyrotron have been started and are ongoing

Thank you for your attendance!

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