Test results and Operational experience of the High Power IOT development for ESS

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Outline of Talk

- RF requirements at ESS and IOT specification
- Outline design
- Test results
- Final thoughts

RF Power Requirements

Design Drivers:

Average Beam Power 5 MW

Peak Beam Power 125 MW

Key parameters:

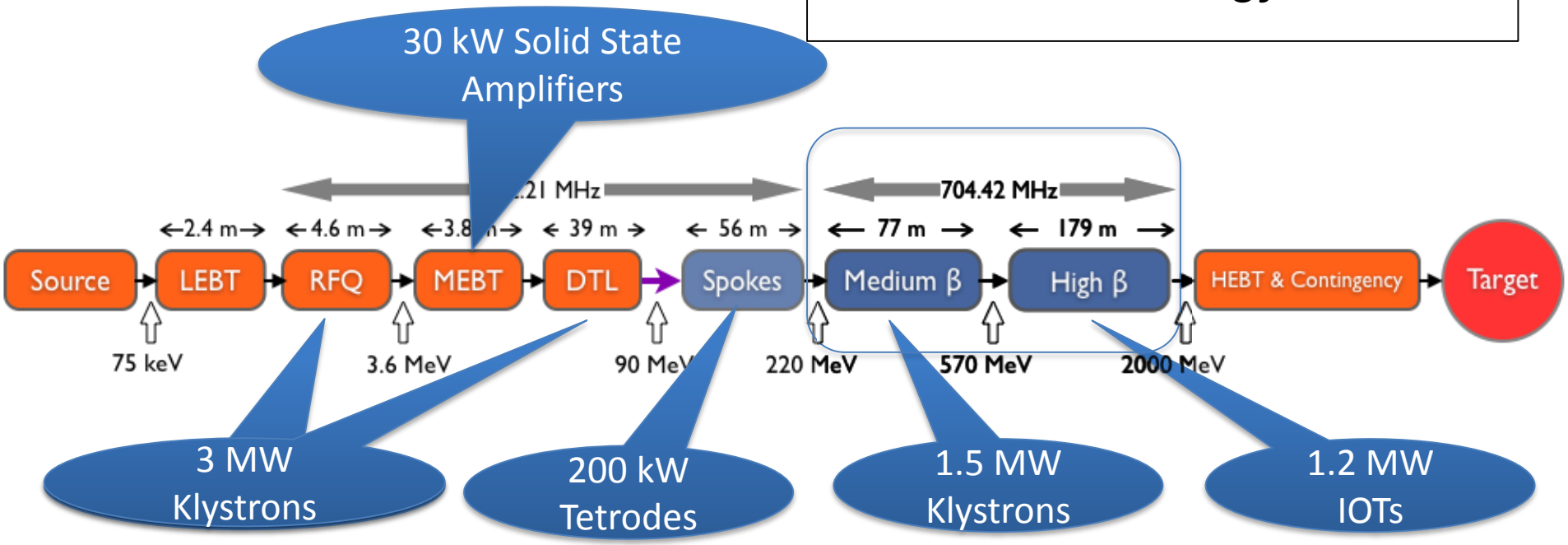
-2.86 ms pulses

-2 GeV

-62.5 mA peak

-14 Hz

-Minimize energy use



MBIOT for ESS

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2014 - ESS signed two contracts for two Technology Demonstrators
Contracts awarded to L3 Inc and CPI/Thales

Parameter		Comment
Frequency	704.42 MHz	Bandwidth > +/- 0.5 MHz
Maximum Power	1.2 MW	Average power during the pulse
RF Pulse length	Up to 3.5 ms	Beam pulse 2.86 ms
Duty factor	Up to 5%	Pulse rep. frequency fixed to 14 Hz
Efficiency	Target > 65%	
High Voltage	Low	Expected < 50 kV
Design Lifetime	> 50,000 hrs	

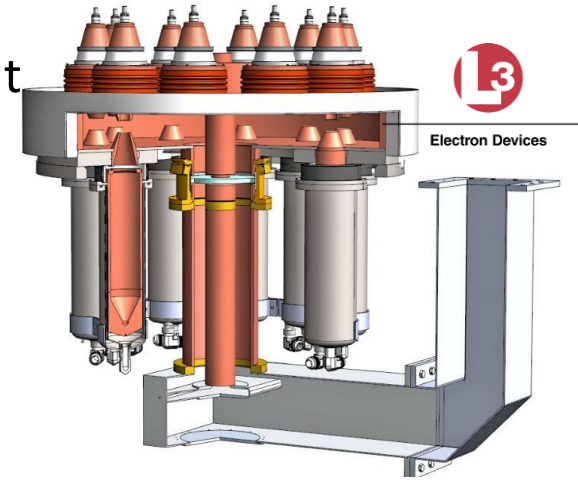
Work was being carried out in collaboration with CERN

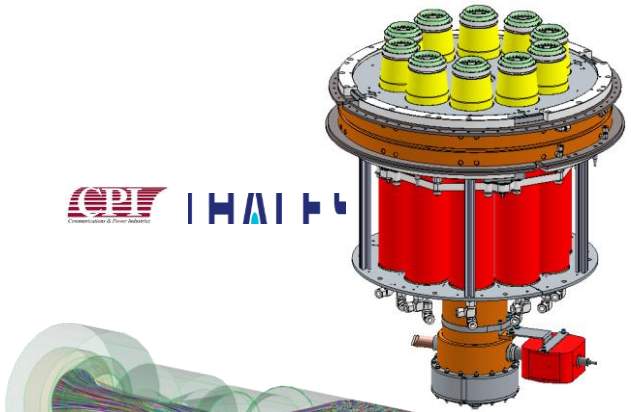
ESS to procure prototypes

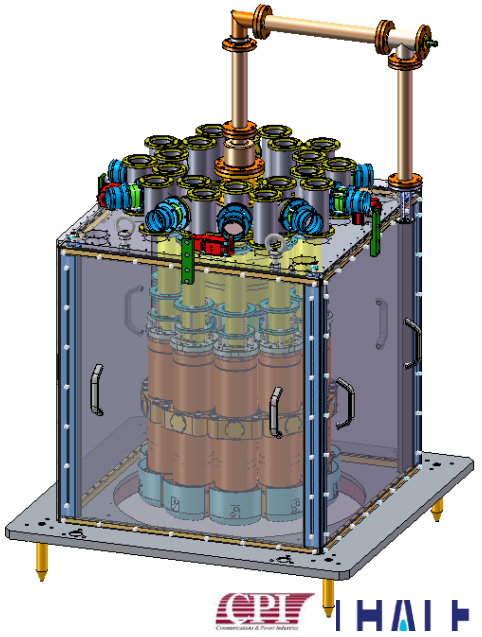
CERN to make space and utilities available for testing

The ESS MB-IOTs

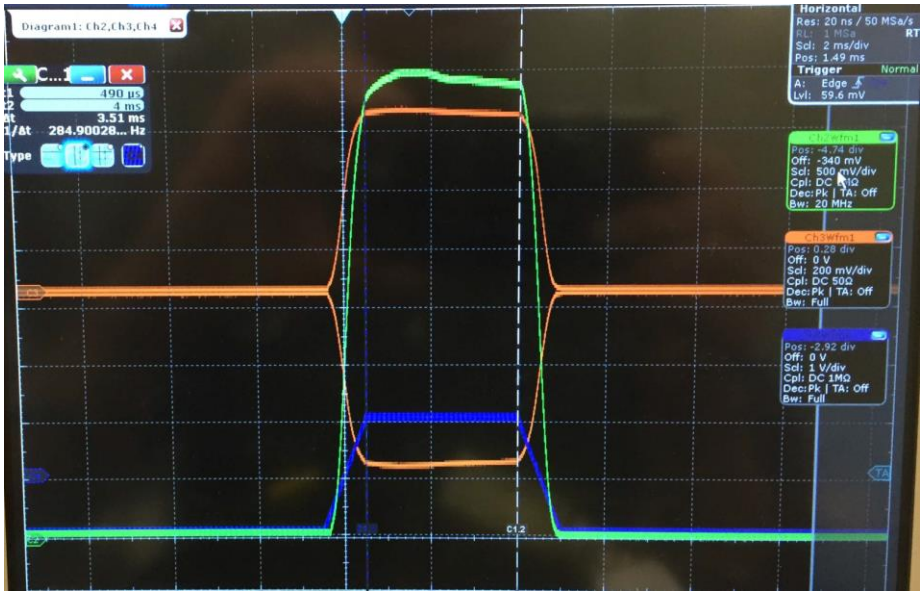
- 10 Electron guns placed in a circle
- Cavity with 10 separate interaction gaps and single output
- Magnetic focusing (PPM or solenoid)
- Output windows based on high power klystron designs
- Extensive modelling and simulation (beam optics, mode analysis, thermal and structural analysis, innovative manufacturing, …
- Single beam prototypes, sub-assembly prototypes, …
- Design driven by reliability and efficiency







Test Results

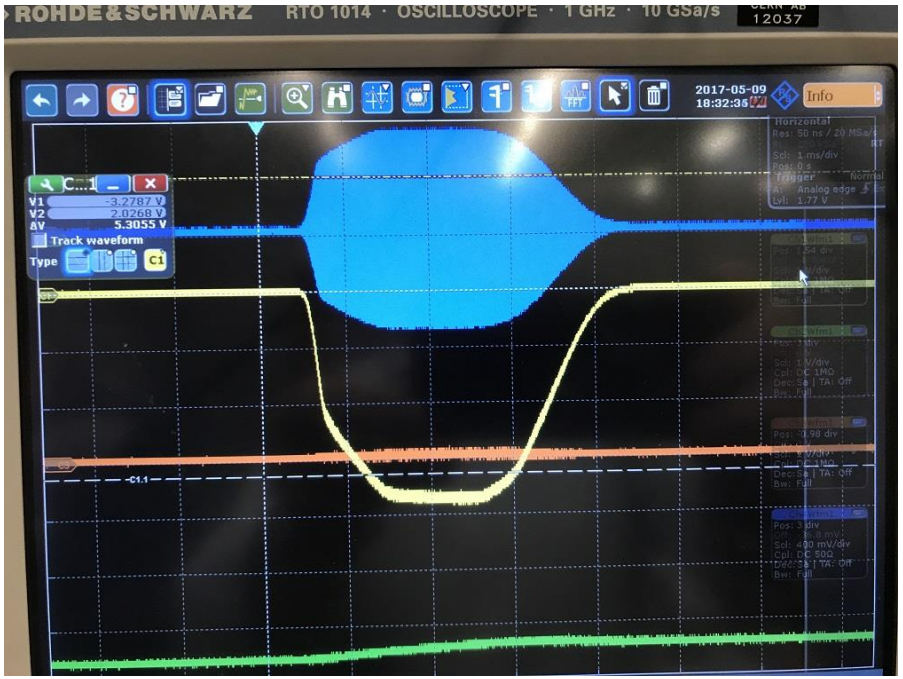


1.2 MW output, 3.5 ms flat top
Rep. Rate = 14 Hz
Cathode current: Green trace
RF Output Power: Orange trace

L3 Electron Devices

Yellow: Total Collector current
Blue: RF output pulse

CPI THALES

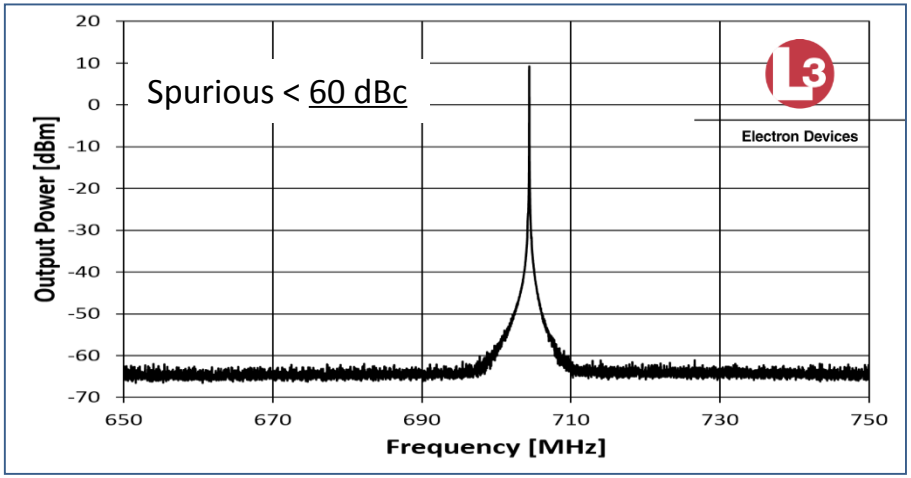


Testing carried out at CERN

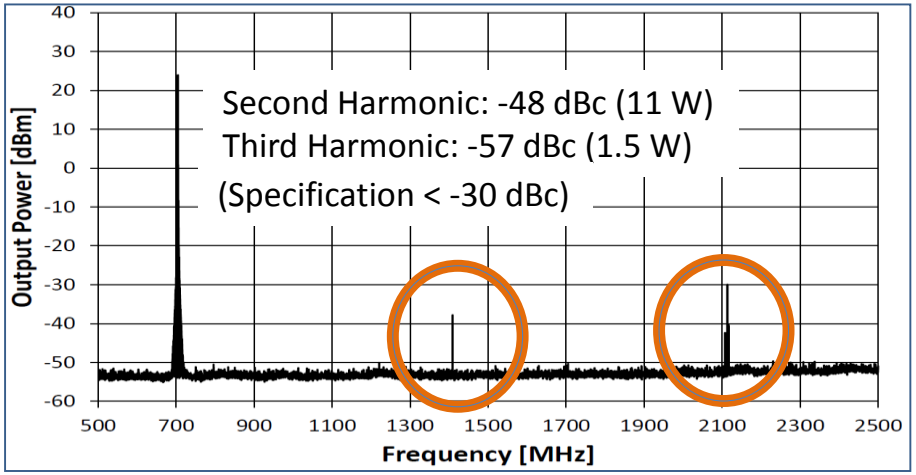
Note: The rise and fall times were introduced due to the crowbar triggering circuit

Test Results

Output spectrum at 1 MW



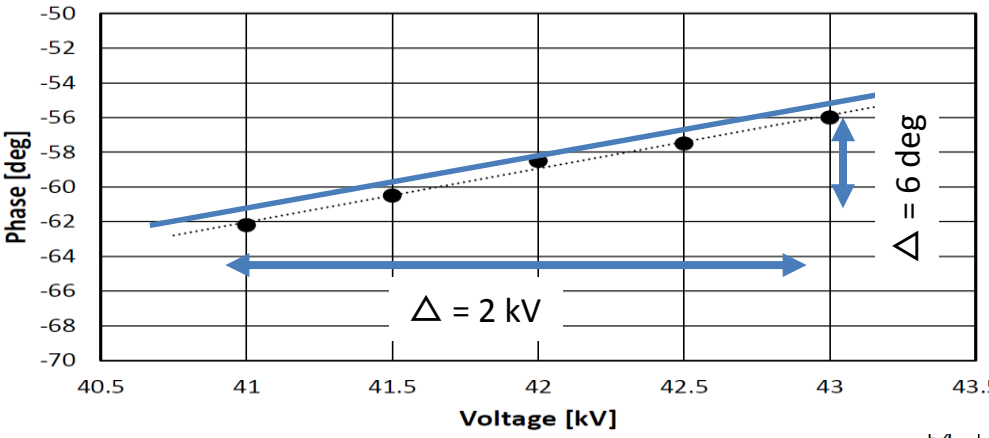
Harmonic content at 1 MW



(Coupling factors calibrated at harmonics)

No power seen from harmonic cavity modes and no sign of instability

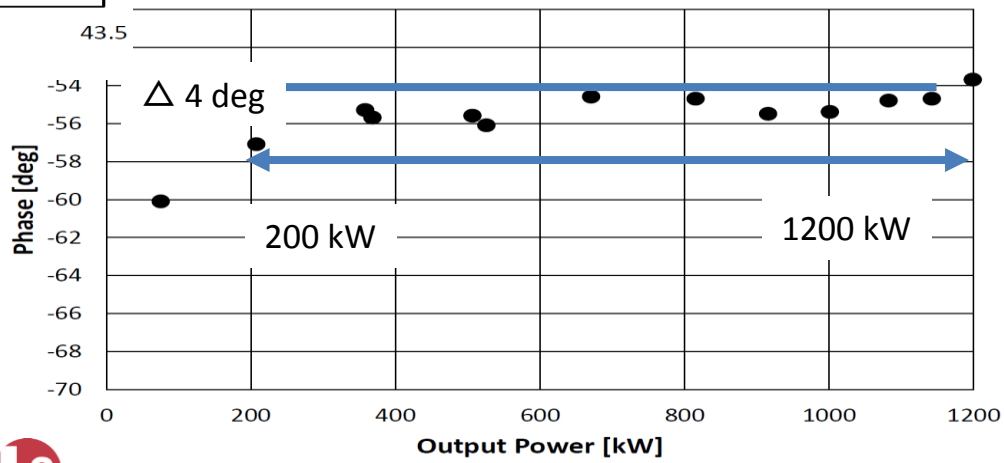
Test Results



- **Low Insertion Phase: 3 deg / kV**
- **Linear and reduces phase variation due to HV ripple**

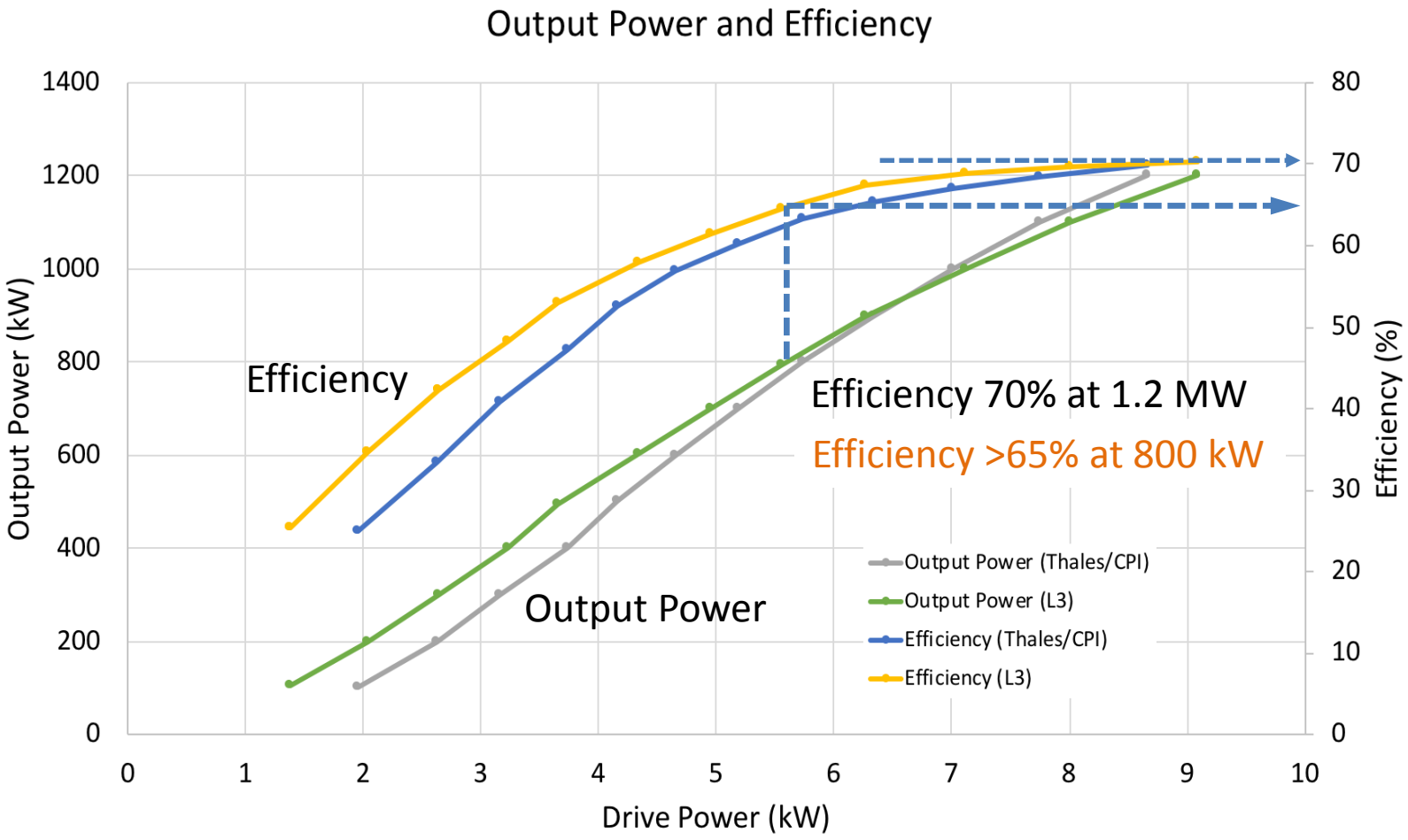
Data taken by varying beam voltage at constant output power (1 MW)

- **Monotonic phase shift for increasing output power**
- **Total phase shift < 4 deg from 20% to 100% of nominal output**
- **Measured at constant beam voltage**



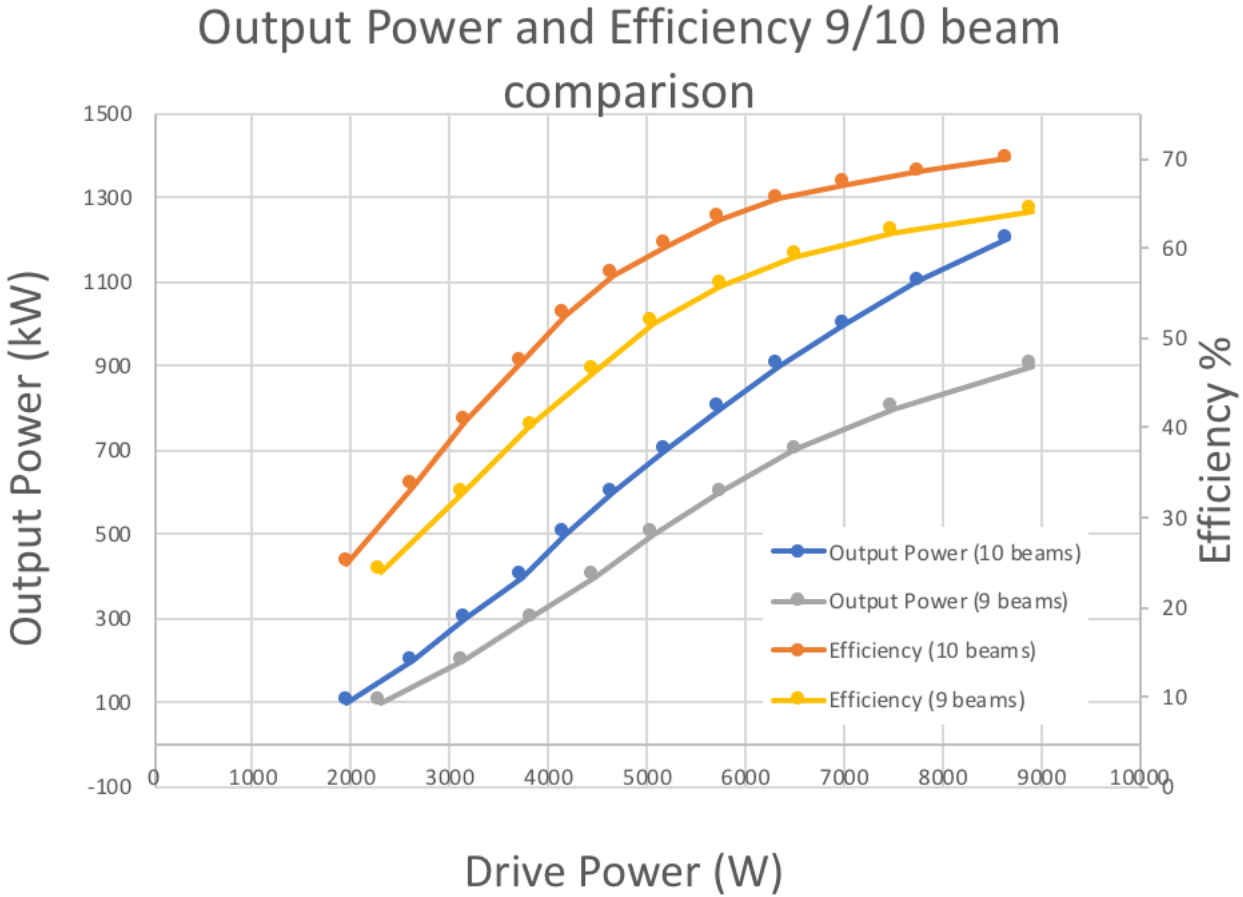
Electron Devices

Test Results



Test Results

Test of Stability and Redundancy



One gun off
Input cavity removed.

No signs of instability

Drive limited due to missing module

Pushing a single gun to higher current, equivalent to 1.4 MW, showed no sign of saturation

Operational Observations

- Initial test setup was not trivial
- Care needed with configuration and design of drivers and auxiliary devices incl. filament, focussing and ion pump supplies
- The first tube on test at CERN was L3. Various trips caused damage to auxiliary supplies and drivers
- Additional grounding installed
- ‘Tricks’ needed to prevent crowbar trips as crowbar was from the LEP cw system

Operational Observations

- L3 IOT continued to suffer from occasional trips disrupting the test stand auxiliary supplies and drivers. Final cause was not identified due to the test schedule

- The Thales/CPI IOT rapidly achieved high power but a poor contact in the output window assembly resulted in rework.
- Following rework full specification was achieved.

- Both IOTs delivered 1.2 MW

- Both IOTs demonstrated possibility of operating with fewer guns in operation

Operational Observations

Looking ahead:

- Dedicated developments for HV PSU, auxiliary supplies are needed to optimise operation (was anticipated)

- Some industrialisation needed to reduce cost, ease operation and improve operational stability

- The MB-IOT is particularly relevant for high duty and high power facilities where a power overhead is required for regulation (i.e. where you cannot operate at saturation)

Test Installation at CERN

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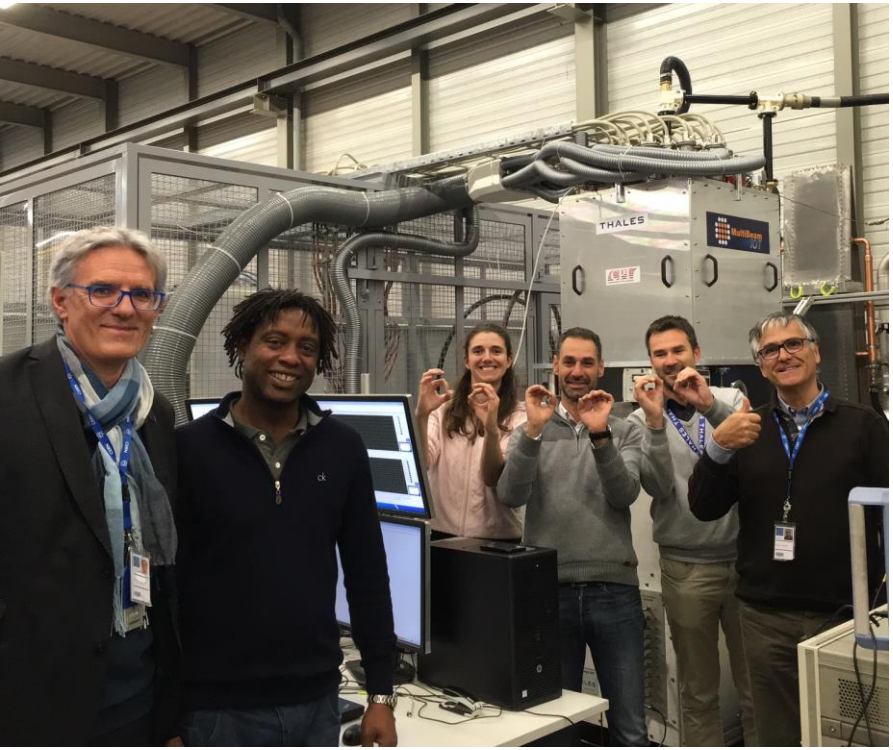
World Record



Thales/CPI MBIOT

L3 MBIOT

Testing at CERN

Conclusion

- ESS and CERN undertook a joint project to procure and test the concept of a high Power MB-IOT for accelerator applications
- Two MB-IOTs were delivered from Industry (L3 Inc and Thales/CPI)
- Both MB-IOTs achieved the specified 1.2 MW.
- Last tests included
  - 1.2 MW with 4 ms pulses
  - 1.35 MW with 1.2 ms pulses and
  - 1.2 MW with 9 beams, 3.5 ms pulses

Quote from Eric Montesinos, CERN

"So, this ends the test bench tests for the MB-IOTs with fantastic results. Thanks to you (and ESS for the funding of the tubes) for having made it possible. Now, we can conclude that the MB-IOT is feasible! Still quite some work until they could be available on the market, but our job is done, and well done!"

The results demonstrate the MB-IOT to be a feasible technology

Acknowledgements

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