Status of the ESS RF Systems and Multi-Beam IOT Test Results

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On behalf of and with input from the RF Section and Partners including:

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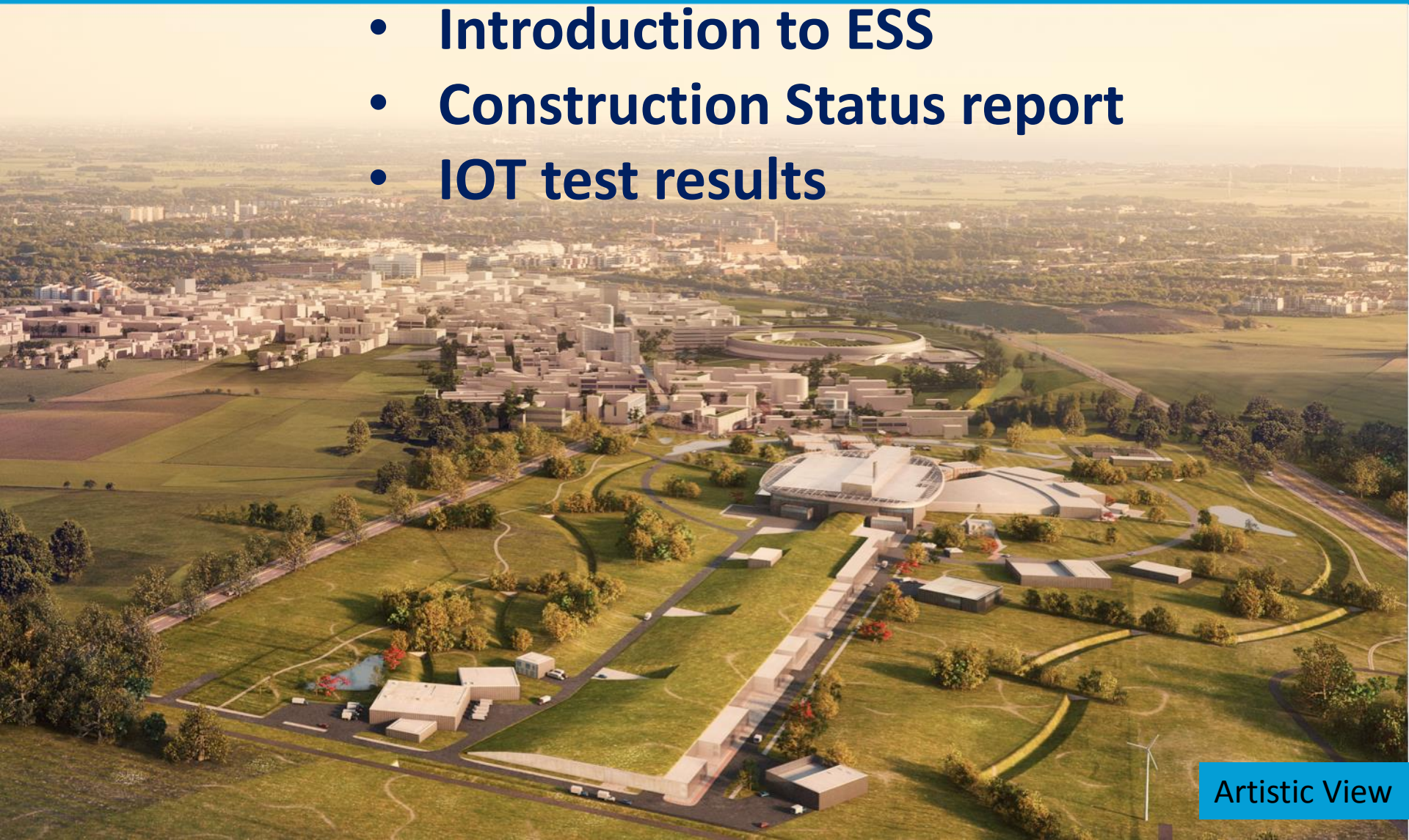
www.europeanspallationsource.se

CWRF 2018 Taiwan

Outline

- Introduction to ESS
- Construction Status report
- IOT test results



Artistic View

Introduction

The European Spallation Source is under construction in the city of Lund, in southern Sweden.

ESS will offer neutron beams of unparalleled brightness for cold neutrons, delivering more neutrons than the world's most powerful reactor-based neutron sources today, and with higher peak intensity than any other spallation source.

Key parameters:

- 2.86 ms pulses
- 14 Hz
- 2 GeV
- 62.5 mA peak
- 5 MW average beam power
- Peak beam power 125 MW
- 155 high power RF stations

RF Scope

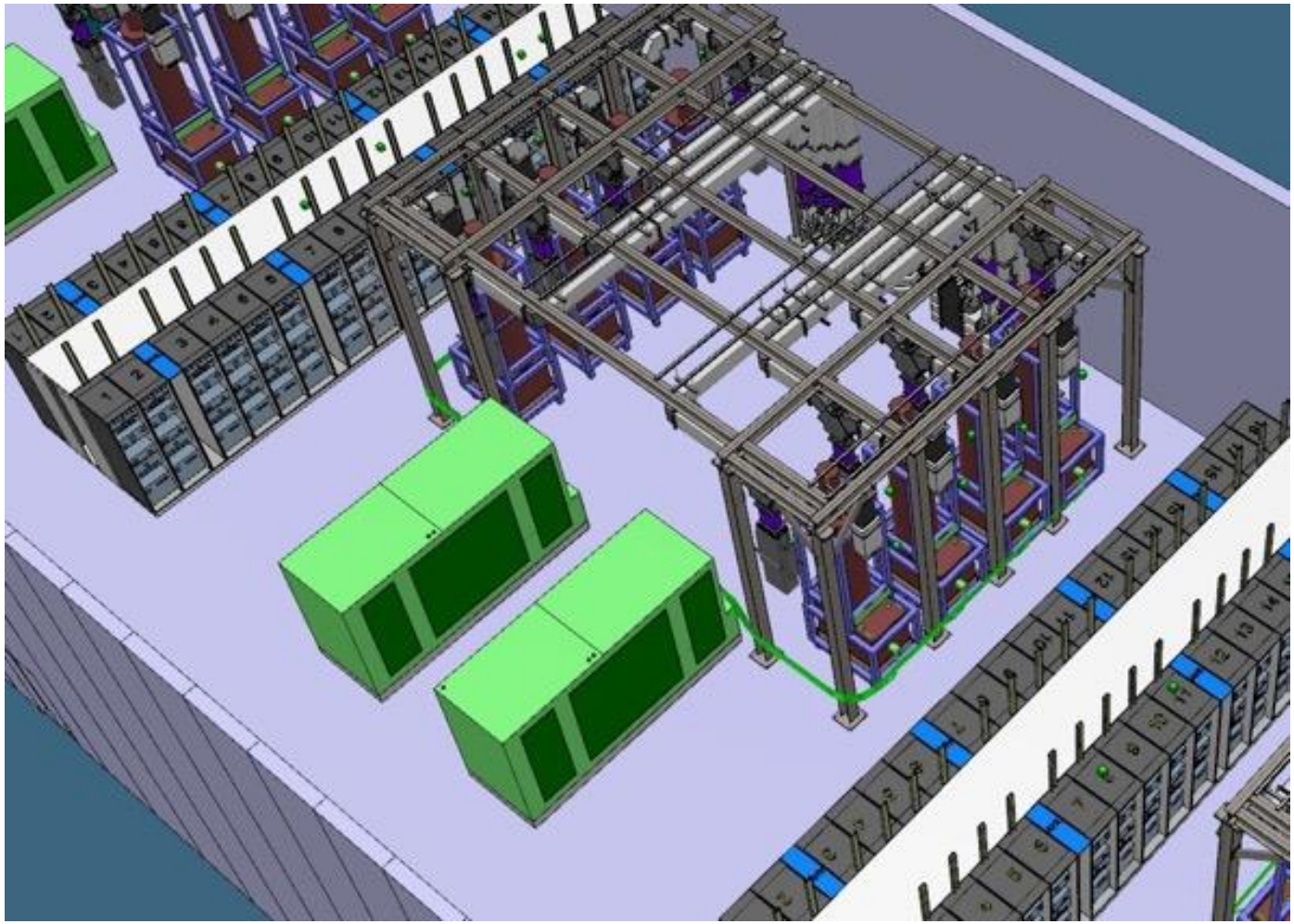
Accelerating Structure	Freq. (MHz)	Quantity	Max Beam Power (kW)
RFQ, DTL	352	6	2200*
MEBT	352	3	18*
Spoke	352	26	330*
Elliptical Medium Beta	704	36	860*
Elliptical High Beta	704	44 (+40)	1100*

155 high power RF stations

* Plus overhead for control

RF Installation, Deliveries and Test Activities

A Typical RF Cell



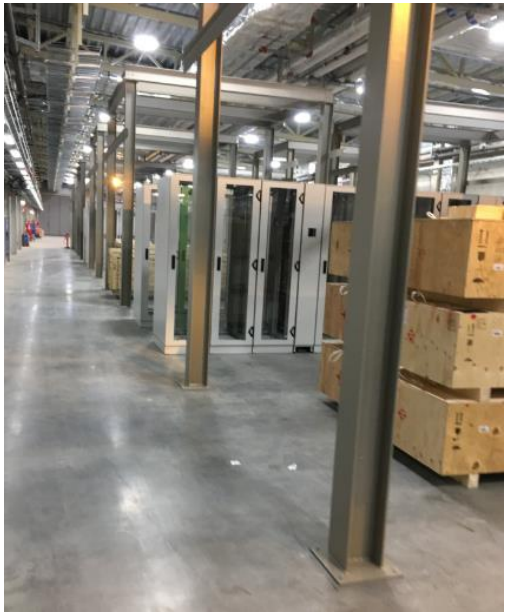
I will focus on the scope of WP8

RFDS: Spoke support structure

Steel was delivered and installed

Paint and transport damage meant repainting

Before



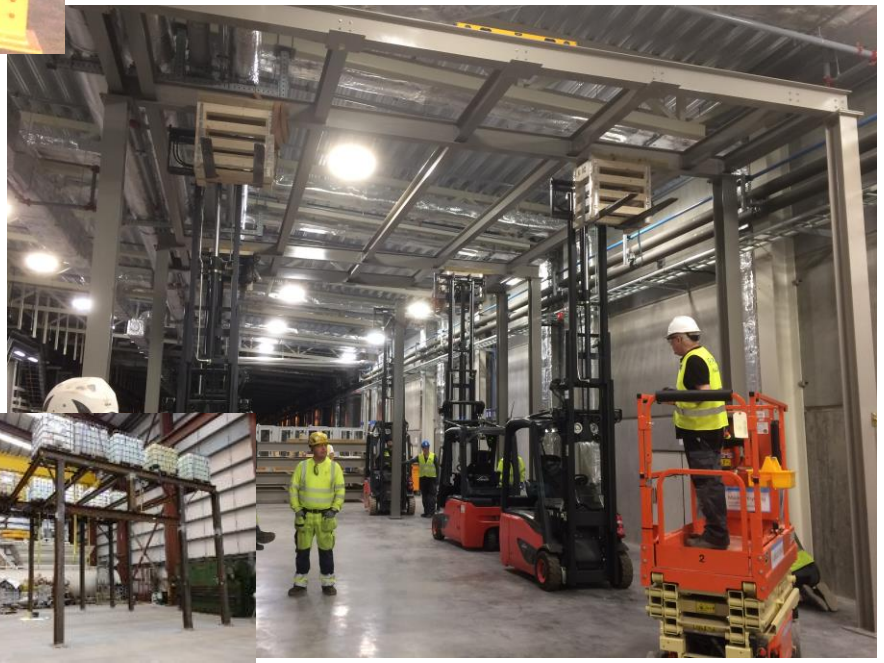
Months of re-negotiation to be allowed to re-paint within the building

MB and HB support structures

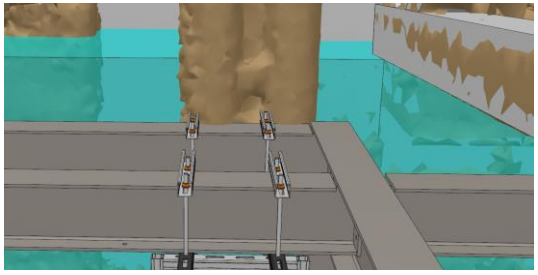
Top structure assembled around 4 forklift trucks

Complicated lift with 4 synchronised forklifts trucks plus a 5th for pillars

First structure erected last week



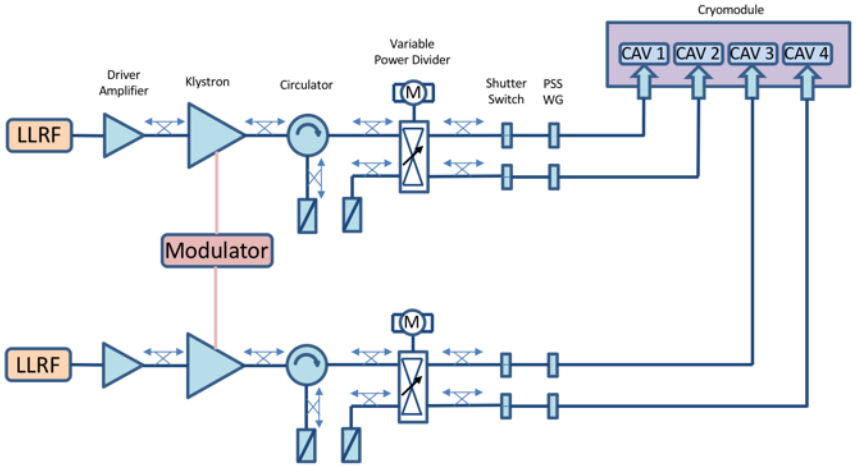
Multiple clashes with pipework, hangers, sprinklers … not within the agreed envelopes



RF Installation and Test Activities in Test Stand 2

Test Stand 2 for cavity testing:
Two klystrons each feeding 2 cavities

Toshiba klystron and interlock system operational for HB cavity testing in Uppsala

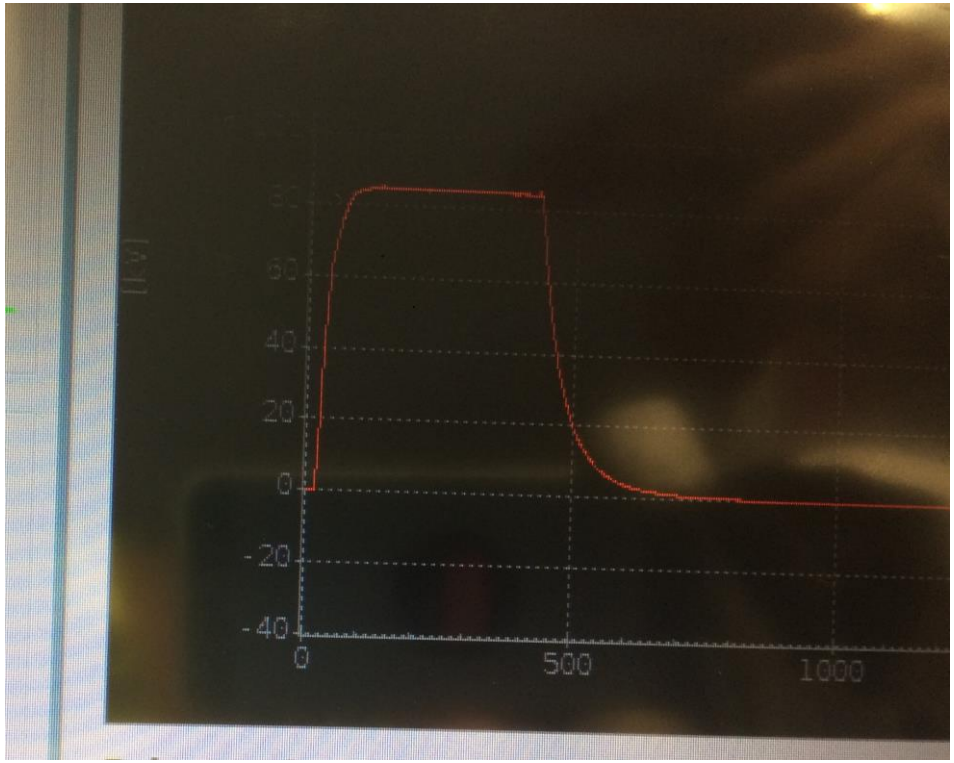


Racks are being used to trial the installation and to see how we optimise power distribution, mechanical supports, cable routing, grounding etc.

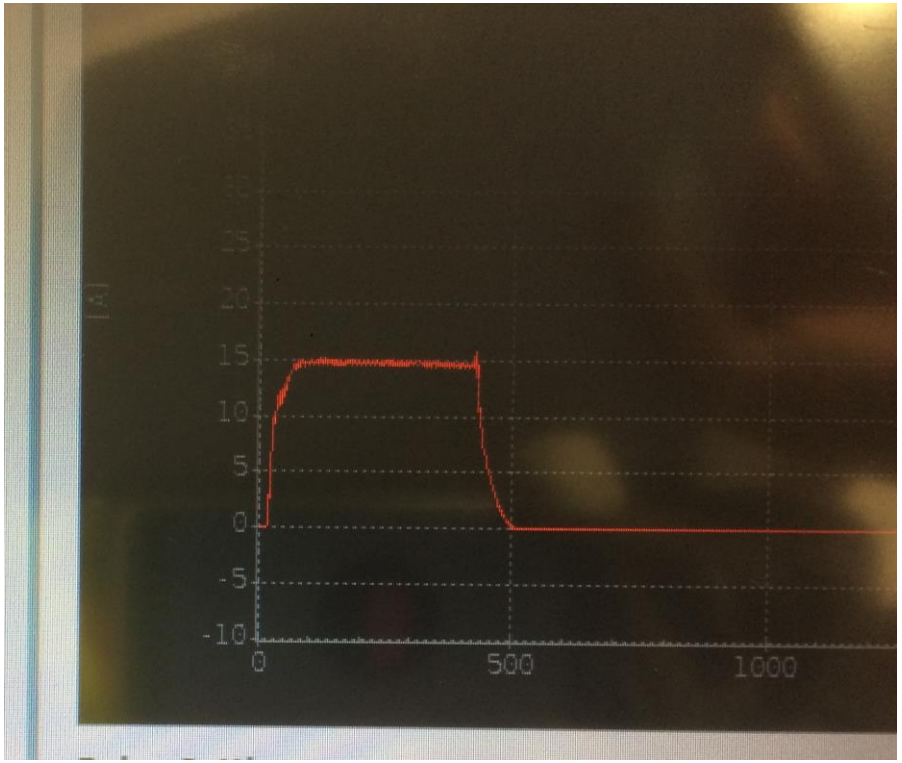
Our First High Voltage Pulse on a Klystron at the ESS Site

EUROPEAN SPALLATION SOURCE

83 kV



15 A



RF Technical Lab at Site Office

Moved in three weeks ago

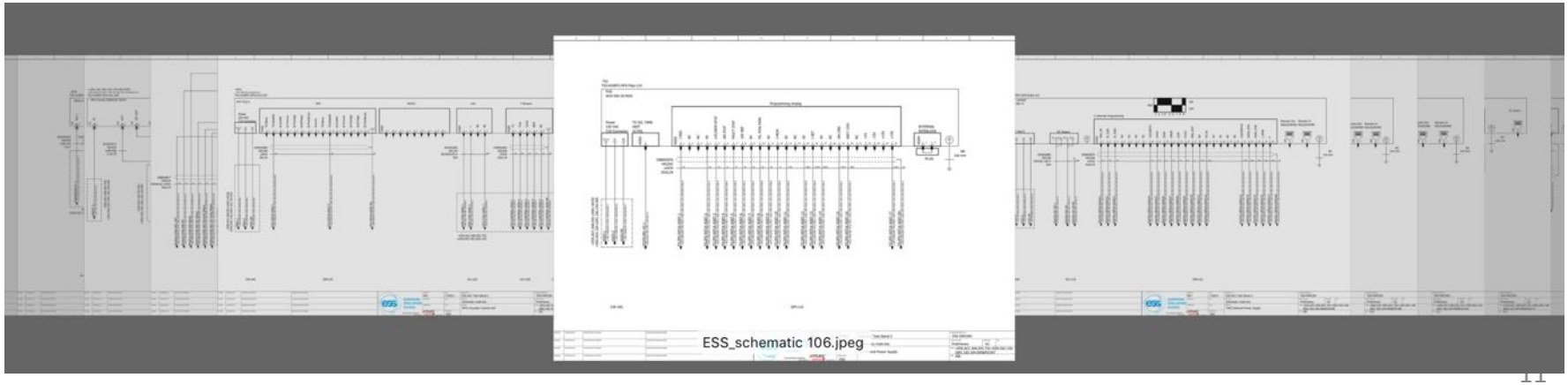
Lab needed for:

- R&D
- Incoming inspections
- Test and setup prior to deployment
- Short term storage
- Extended testing

Cable Database, Rack Layout, Electrical Schematics being done in-house

Detailed information for **15’000 RF system cables** already in now database

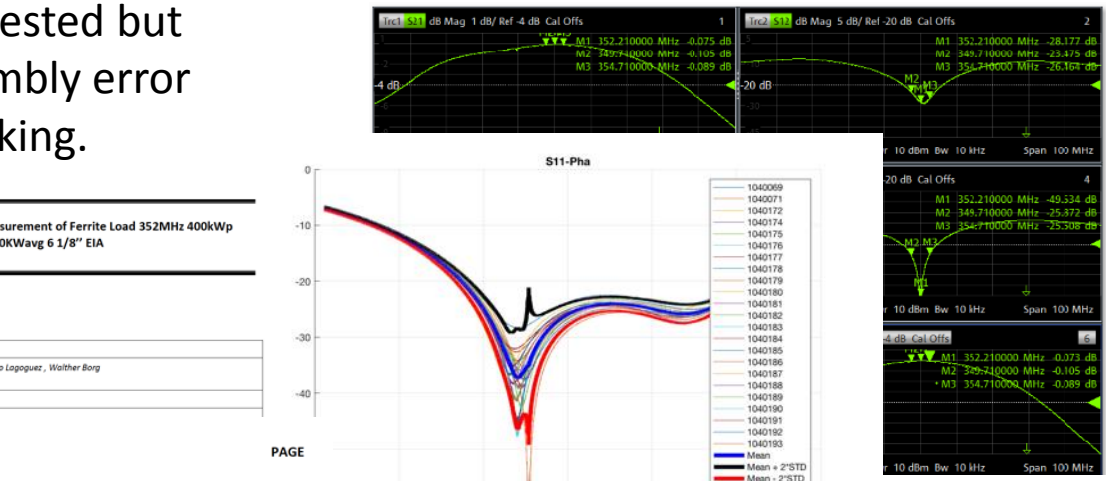
Electrical schematics and drawings for rack layout and installation

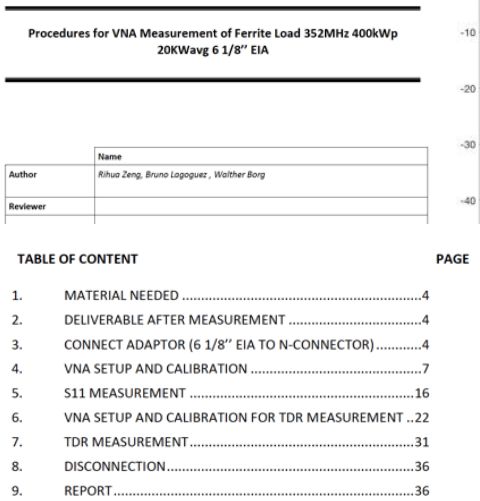


Deliveries, incoming inspections, testing and storage

Spoke circulators: 352 MHz, 400 kWp

26 circulator received and low power tested but the vendor discovered a possible assembly error and the units will be returned for checking.



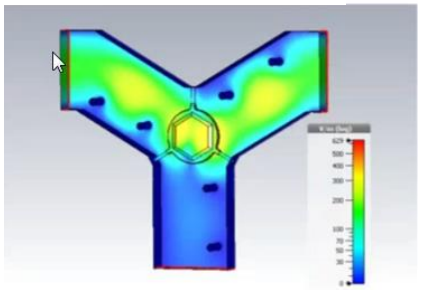


Procedures for VNA Measurement of Ferrite Load 352MHz 400kWp
20KWavg 6 1/8" EIA

	Name
Author	Rihua Zeng, Bruno Lagoguez , Walther Borg
Reviewer	

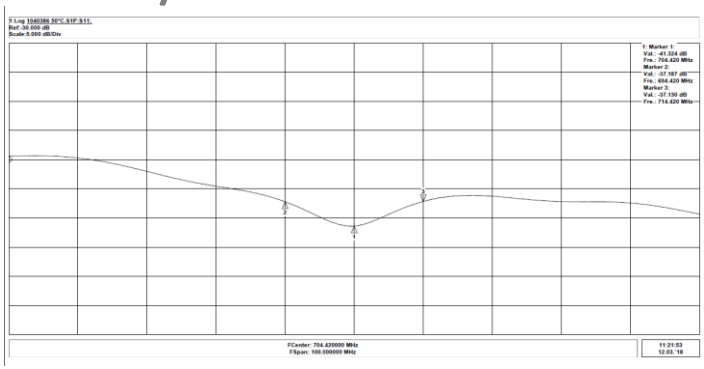
TABLE OF CONTENT PAGE

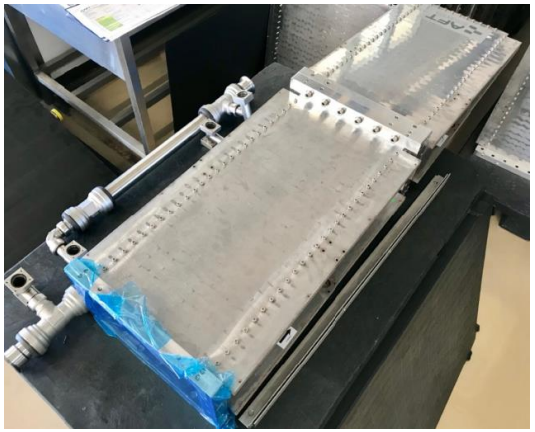
MB/HB circulators: 2 designs performed and prototypes tested at low power. Parasitic resonance risk. High power test to be done soon.



- Spoke loads: 26 loads received and tested at low power.

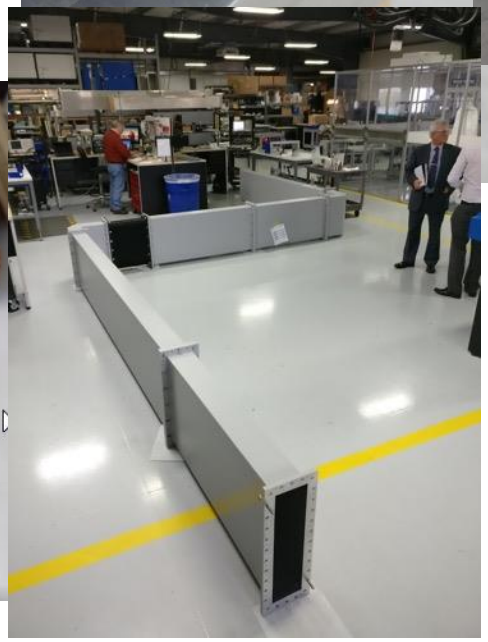
- MB/HB loads:





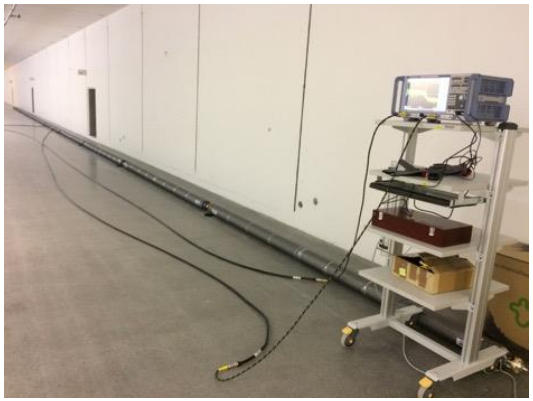
Waveguides

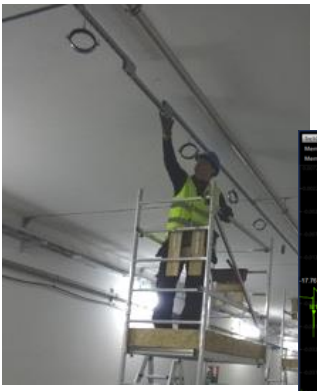
- Approx 5000 pieces
- Delivery of 22 (many hand packed) containers has started
- Serious issues with dirt and twist

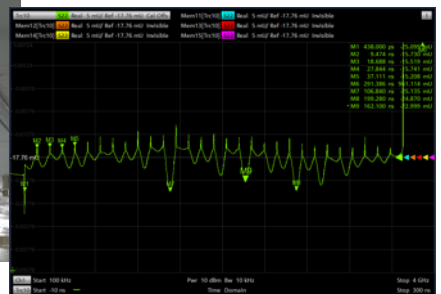


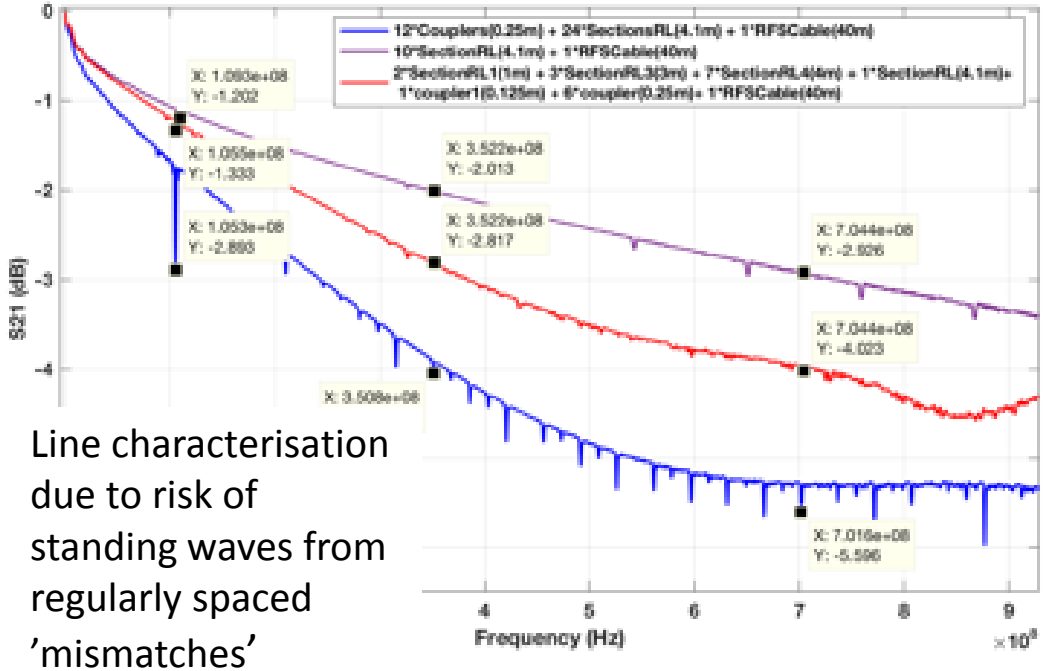
Phase Reference Line

500m PRL line installed from ion source to Dogleg
~100m PRL line remain to be installed
119 rigid line sections *with*
- *heating cables, Temperature sensors*
- **53** directional couplers









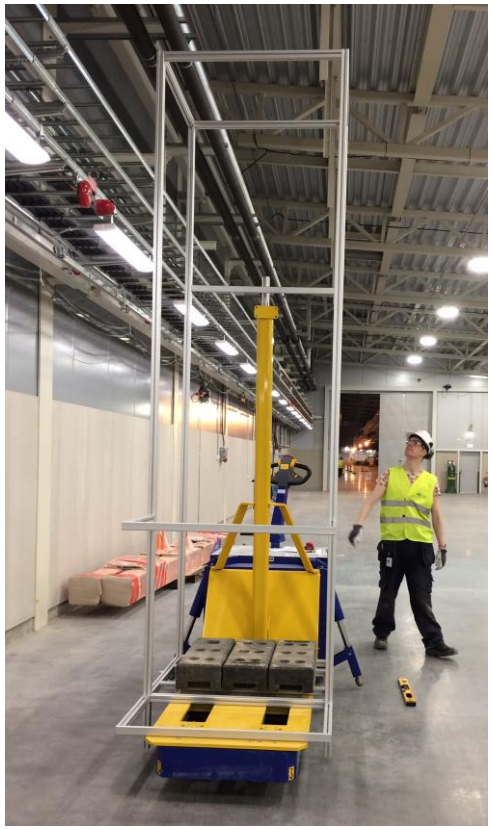
Line characterisation due to risk of standing waves from regularly spaced 'mismatches'

Pedestals, Nuts and bolts

- Including 144’000 waveguide nuts and bolts!

Mechanical supports

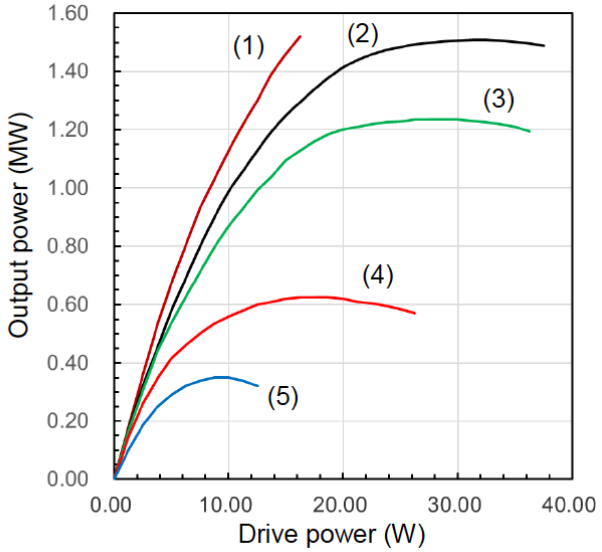
1.5 MWp, 704 MHz Klystrons

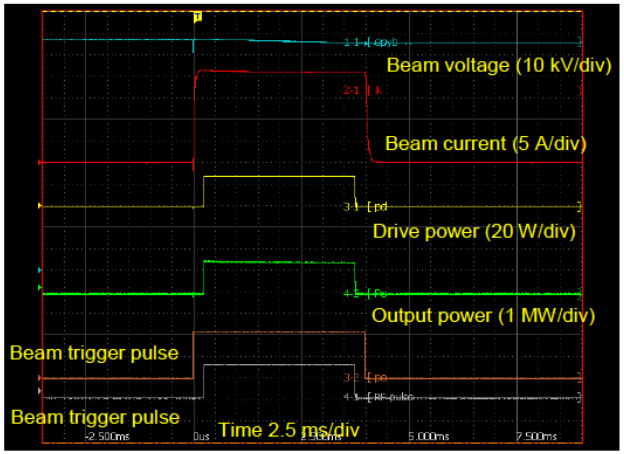


Bespoke klystron truck procured and test run

- **Three prototypes**
  - Toshiba Prototype currently in operation in Uppsala
  - CPI Prototype installed in TS2: High power testing started
  - Thales Prototype in TS2: Awaiting test
- **Medium Beta Series (18 Toshiba, 18 CPI)**
  - Three shipped, 1st klystron being delivered to 27th June
  - 4th on test
  - CPI deliveries start in September
- **Tenders being prepared for High Beta part 1 – 44 units**
- **4 klystrons per modulator**

Toshiba FAT, some results



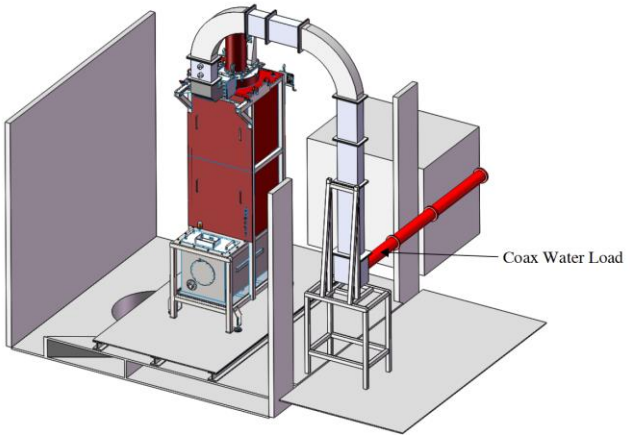


(a): Waveforms of beam voltage, beam current, drive power and output power for 1.5-MW operation

No.	Beam voltage (kV)	Beam current (A)	Solenoid current		RF power (MW)	Iris
			1	2		
1	115.0	23.6	10.0	10.0	1.51	
2	106.4	21.2	10.0	10.0	1.52	
3	98.0	18.7	9.0	8.5	1.23	
4	75.0	12.7	7.0	8.0	0.625	Iris 1
5	61.2	9.4	5.5	7.0	0.350	Iris 2

1st CPI klystron to be tested at the beginning of September

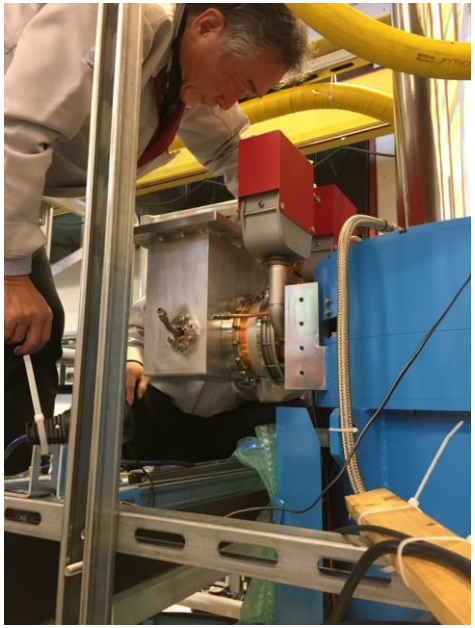
MSR Test Stand Layout for the VKP-8292A Klystron for ESS

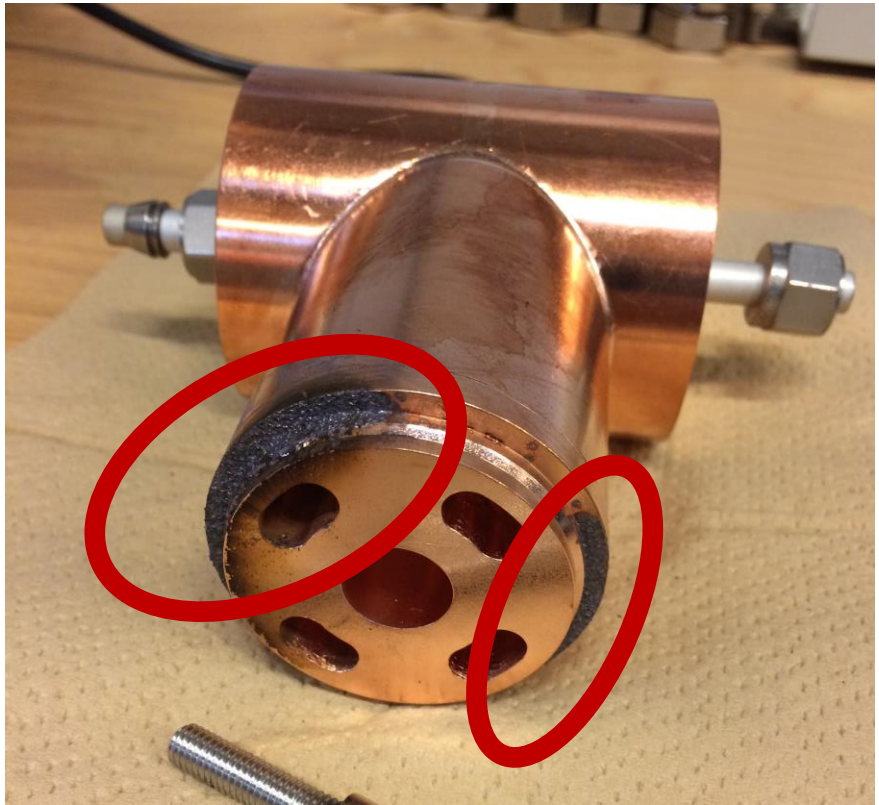


Delivery of the first ESS MB Klystron on 27th June 2018

(The official) Problem Slide

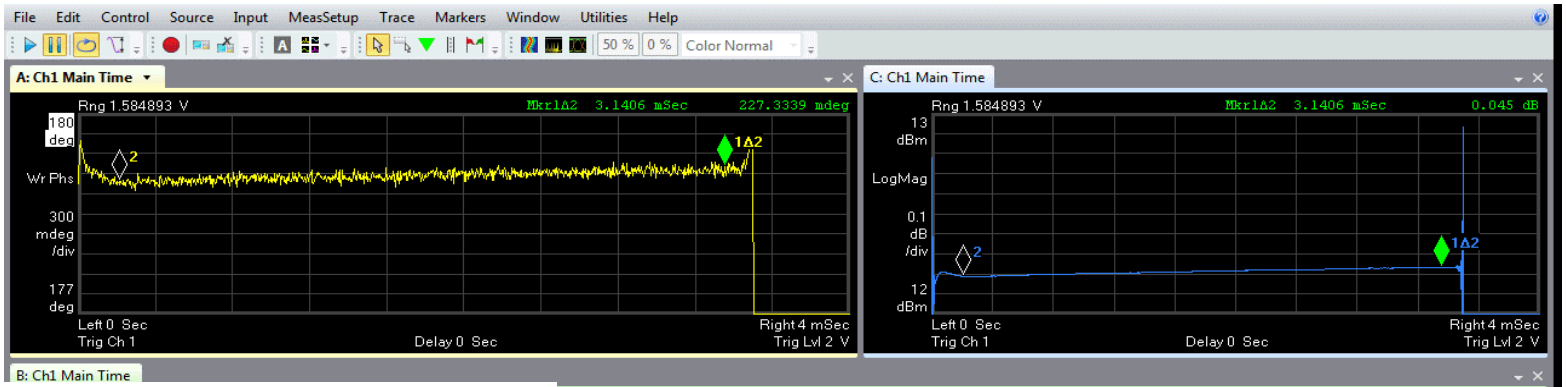
- December 2017: Arc detector trips observed during the testing of the Toshiba klystron prototype.
- Cause identified in RF discharge in the T-bar transition of the output circuit
- Toshiba re-designed the part and came for repair

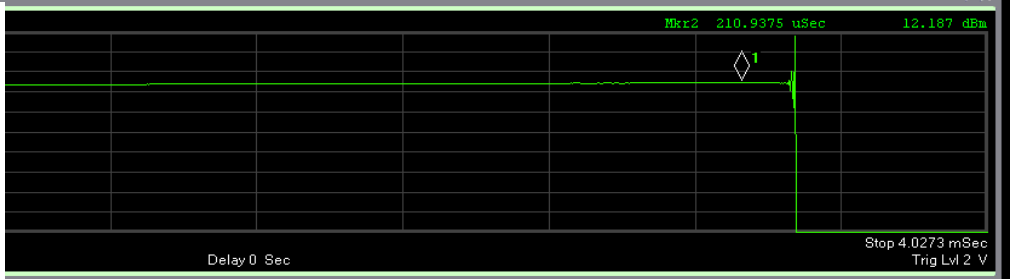


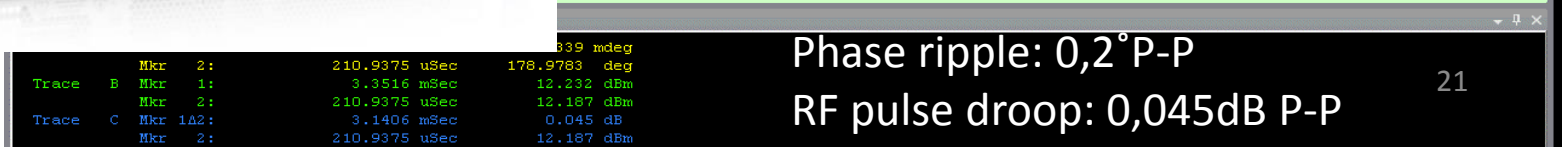


Solid State Drive Amplifiers for MB/HB

- R&S chosen, frame-work in place for up to 120 units
- 1st prototype measured
- 2 pre-series units received
- Site testing started last week - will release the next batches





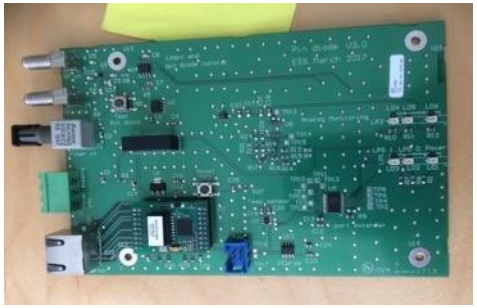


Phase ripple: 0,2˚P-P

RF pulse droop: 0,045dB P-P

Splitter box, E- Pick up and Pin diode

- Splitter boxes designed and under test
- Pin diodes units and PSS RF switches designed and under manufacture



Arc detectors

- Order placed for gallery arc detectors (> 500). Delivery planned in 3 months (approx.)
- Validation done on prototype (thanks to STFC)
- Technology for arc detectors for the tunnel under consideration

Please share your experience and comments on ADs for the tunnel

LLRF

- LLRF prototypes has been running in two test systems in Lund and two in Uppsala.
- Main digitiser boards have been updated to latest version of FPGA hardware, and now have a newly developed AXI-framework running
- Additional modules incl Piezo drivers + PSUs and LO being developed by in-kind partners in Poland. Design complete and in manufacture.
- Procurement and assembly of the first in-house master oscillator progressing with the first unit expected by end of 2018

An IOT for ESS

ESS placed contracts for two **Technology Demonstrators**

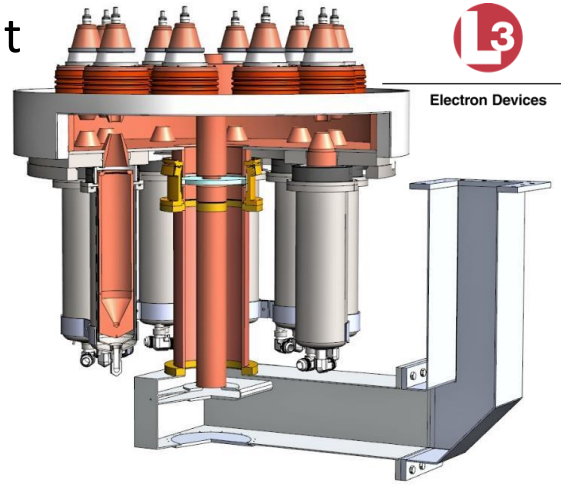
- *L3 Electron Devices*
- Consortium of *Thales Electron Devices (TED)* and *Communications & Power Industries (CPI)*

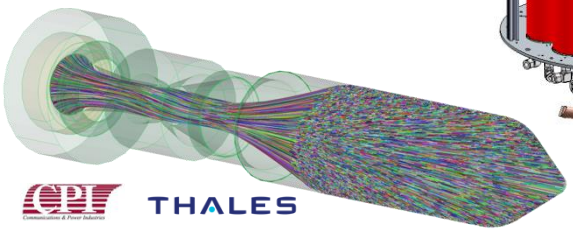
Key Parameters	Specification
Frequency	**704.42 MHz**
Maximum Power	**1.2 MW**
RF Pulse length	Up to 3.5 ms (@ 14 Hz)
Duty factor	Up to 5%
Efficiency	Target > 65%
High Voltage	< 50 kV
Design Lifetime	> 50,000 hrs

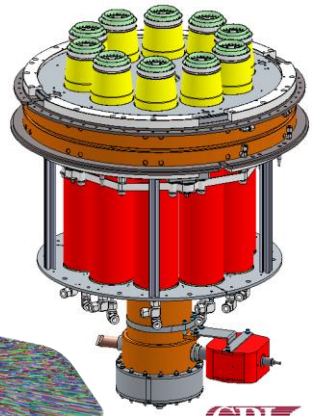
- CERN to set up a test stand and carry out site testing

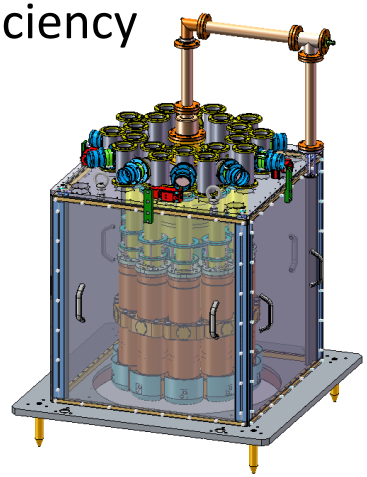
The ESS MB-IOTs

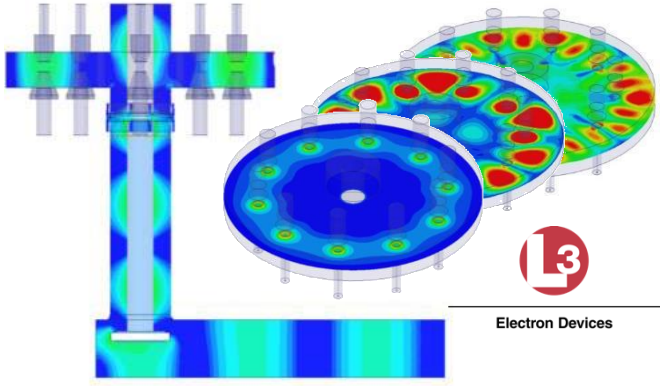
- 10 Electron guns placed in a circle
- Cavity with 10 separate interaction gaps and single output
- Magnetic focusing (Permanent magnet or solenoid)
- Output windows based on high power klystron designs
- Suppliers carried out extensive modelling and simulation (beam optics, mode analysis, thermal and structural analysis, innovative manufacturing, …)
- Manufacturing validation through single beam prototyping and sub-assembly test vehicles, …
- Design driven by reliability and efficiency











From Simulation to Reality: L3

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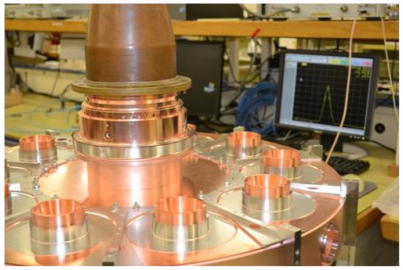
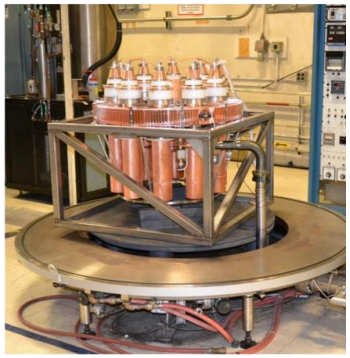
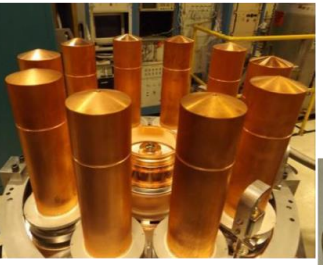
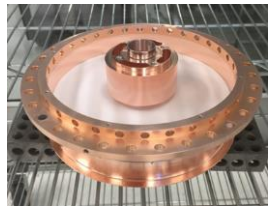




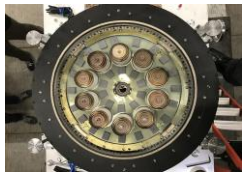


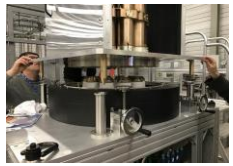
L3 Electron Devices



CPI Communications & Power Industries

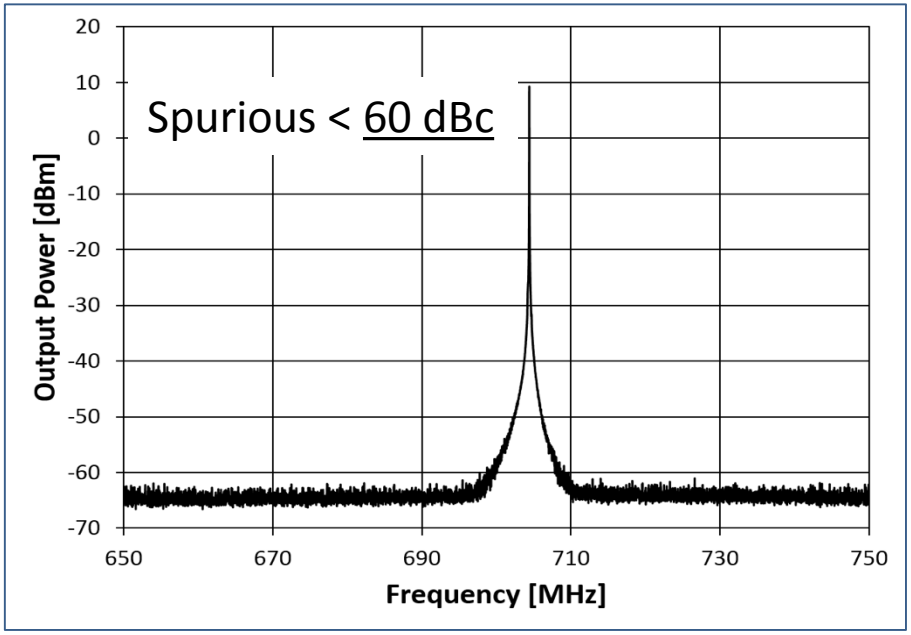
THALES



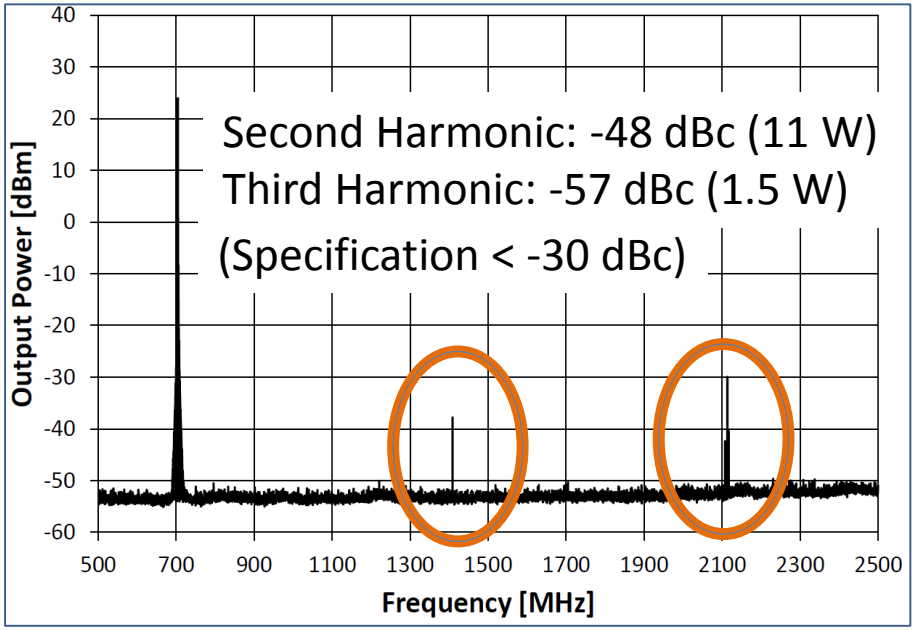


L3 IOT Factory Acceptance Results

Output spectrum at 1 MW



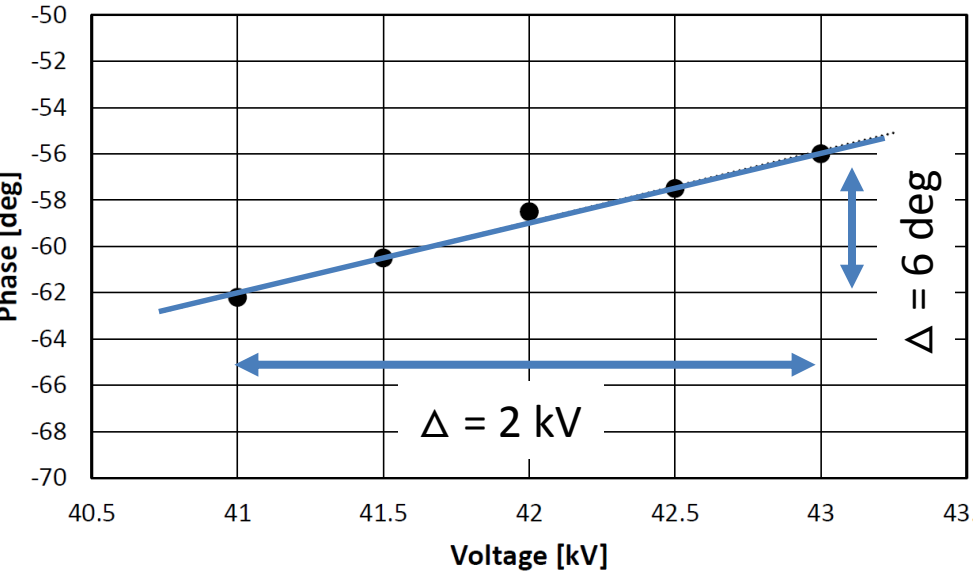
Harmonic content at 1 MW



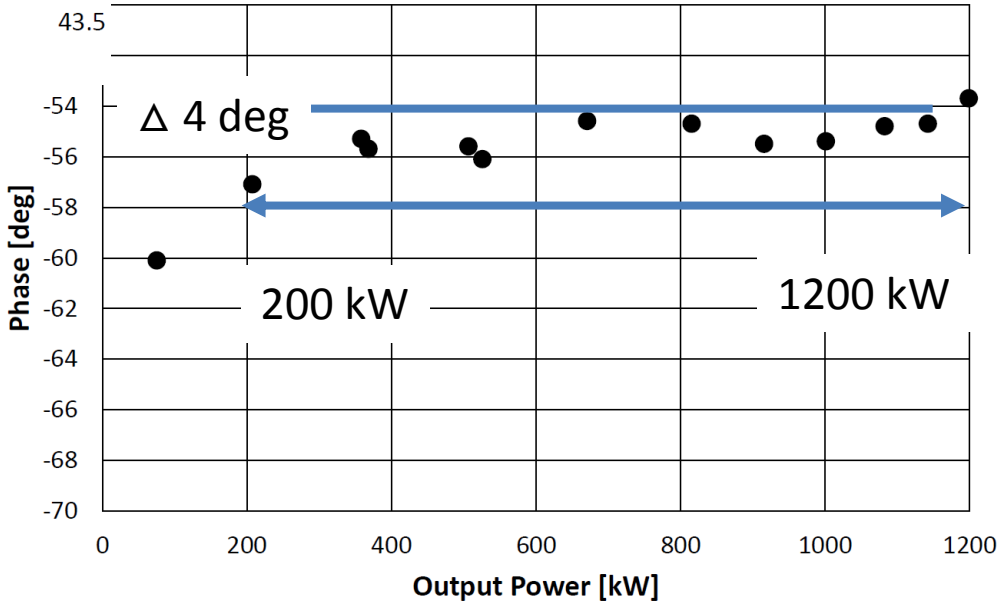
(Coupling factors calibrated at harmonics)

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

L3 IOT Factory Acceptance Results

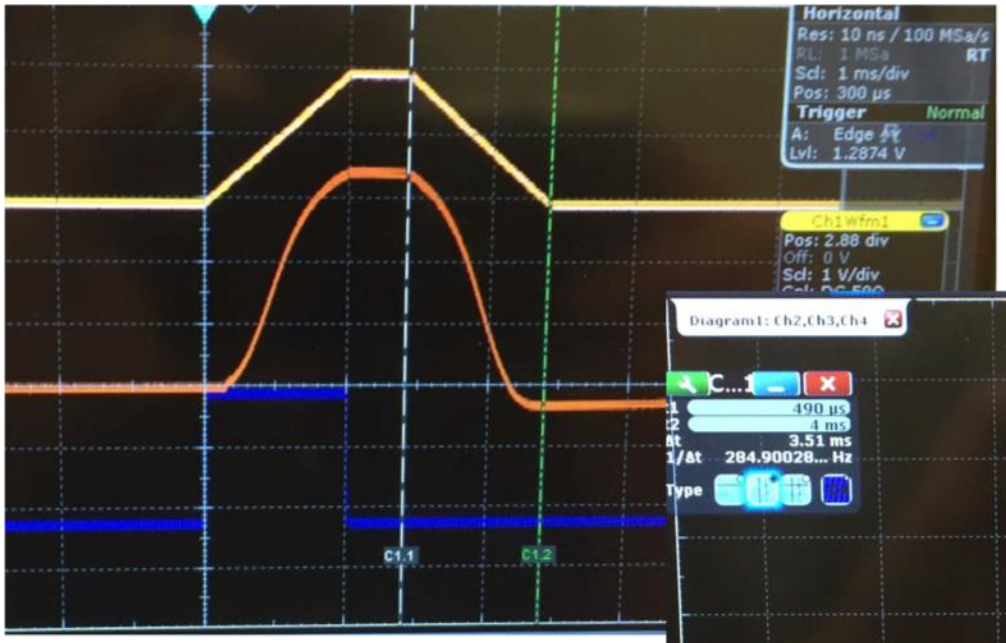


- **Low phase shift as a function of HV**
- **Low phase shift as a function of output power**

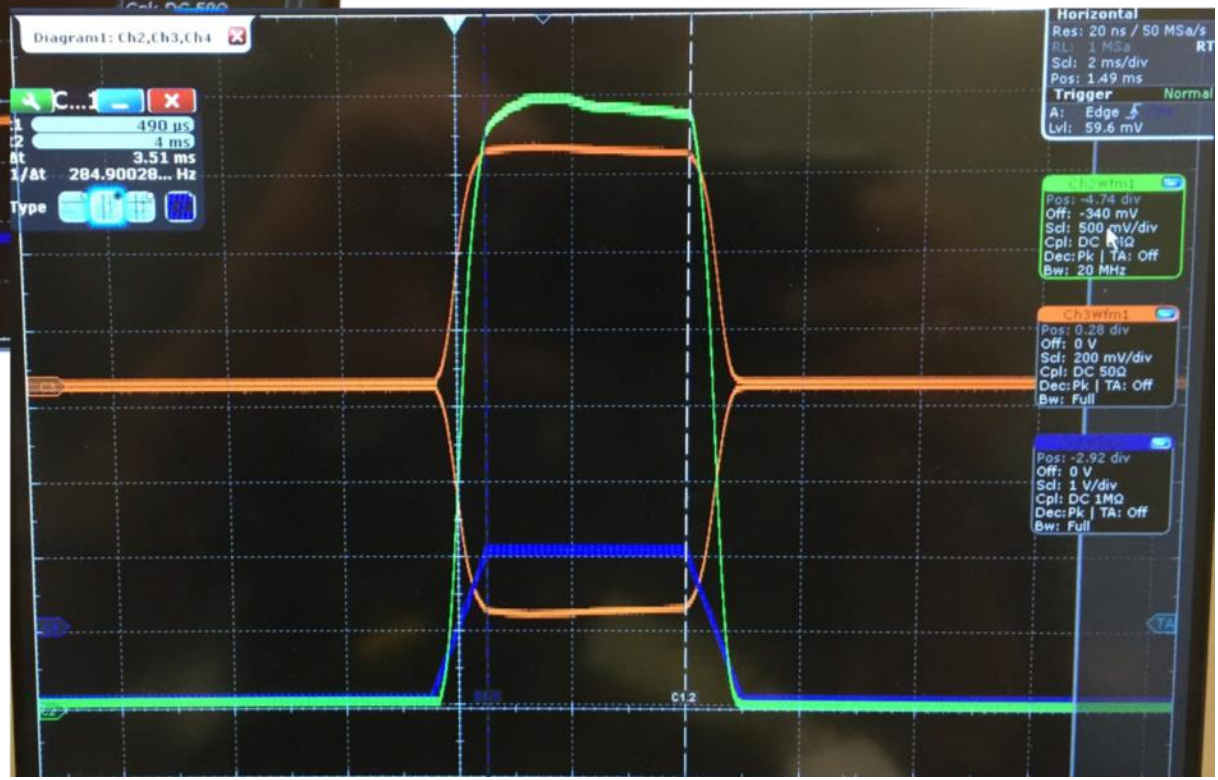


Data taken by varying beam voltage at constant output power (1 MW)

L3 IOT Results



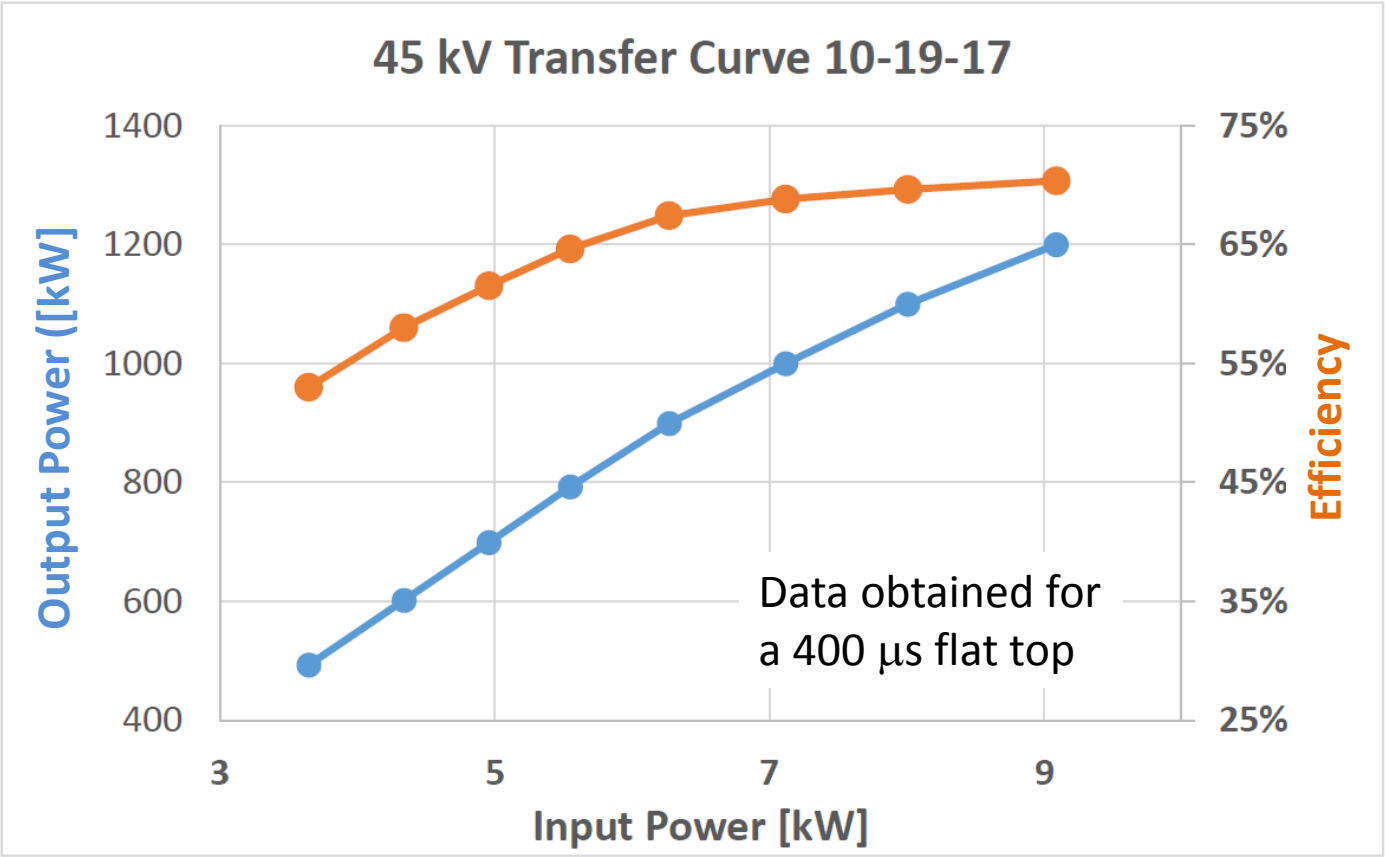
Scope capture with 400 µs flat top
Input Drive: Yellow trace
RF Output Power: Orange trace



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

Testing carried out at CERN

L3 IOT Results

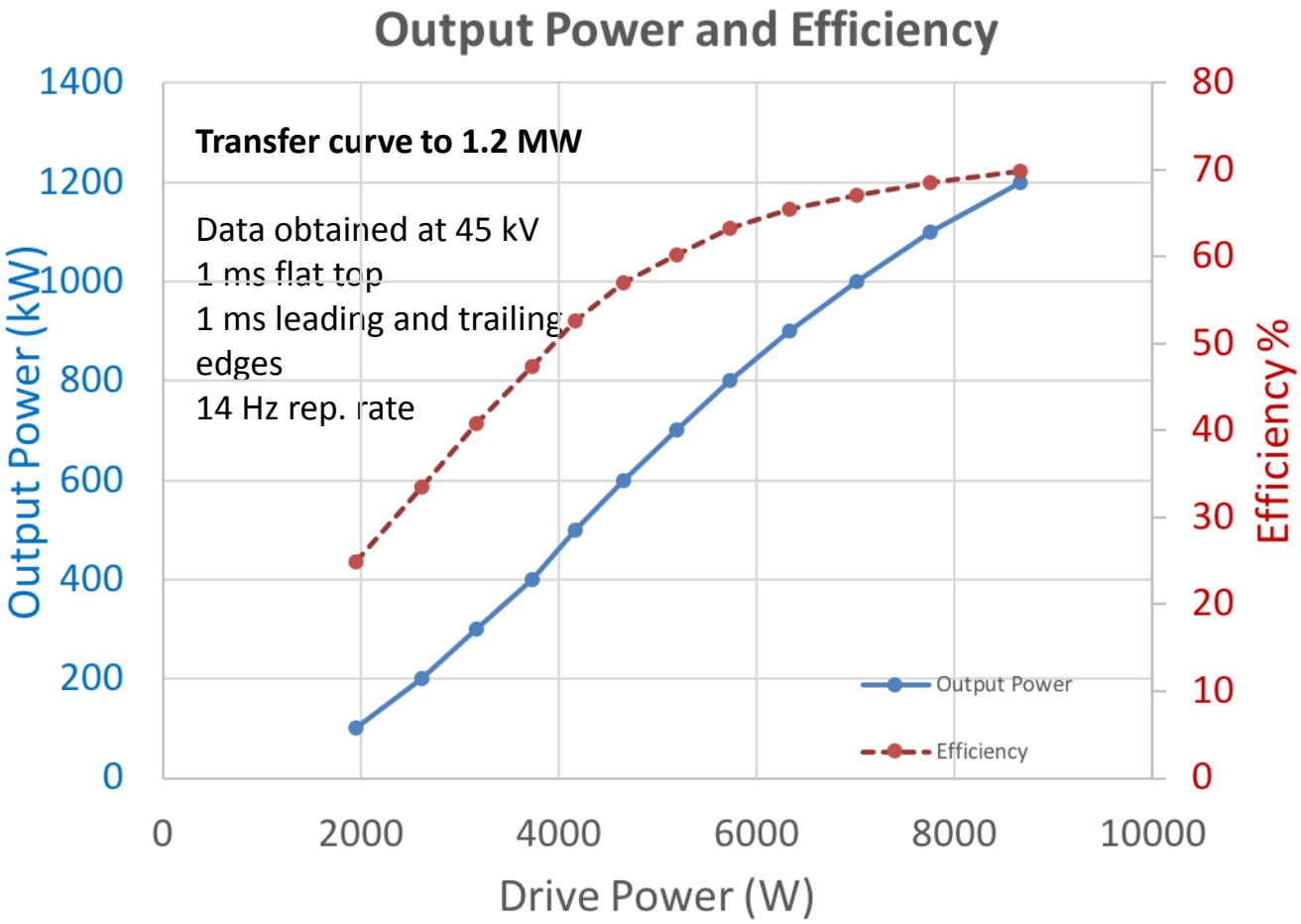


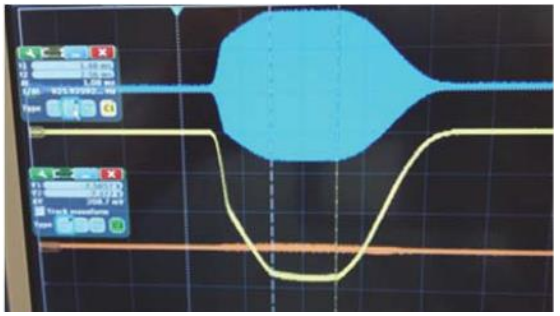
Long pulse operation:

1.2 MW achieved with 3.5 ms flat top with 1 ms ramps on leading and training edges

1.14 MW achieved at 4 ms flat top, limited by the drivers

TED/CPI IOT Results





Yellow: Total Collector current
Blue: RF output pulse

IOT installed at CERN

MBIOT Status

MBIOTs delivered to CERN for testing
Both MBIOTs have delivered 1.2 MW
Overall Technical Specification achieved

World Record

Thales/CPI MBIOT

L3 MBIOT

Testing at CERN

IOT Conclusion

- ESS, together with industry, delivered two successful technology demonstrators
- Budget, schedule and risk constraints at ESS means that ESS must opt for klystrons for the first part of the high beta linac
- ESS will continue to follow the development and hope that new high power accelerators will be able to benefit from the investment
- The MB-IOTs developed for ESS have been constructed using CW capable components. High power CW operation could result in a payback time of 1 – 2 years through savings in electrical cost