



**EUROPEAN
SPALLATION
SOURCE**



Radiofrequency Systems at ESS

**PRESENTED BY:
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RF GROUP LEADER / WP MANAGER / MACHINE SECTION COORDINATOR**

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ESS design

High Power Linear Accelerator:

- Energy: 2 GeV
- Rep. Rate: 14 Hz
- Current: 62.5 mA

- ### Target Station:
- He-gas cooled rotating W-target (5MW average power)
 - 42 beam ports

16 Instruments in
Construction budget

Committed to deliver 22
instruments by 2028

Peak flux -30-100 brighter
than the ILL

Total cost: 1843 MEuros ₂₀₁₃



From Green Field to ESS

May 2014



April 2022



Tunnel view then and now





Klystron Gallery Then and Now



RF for normal conducting linac is installed, tested and in operation.



Installation and testing ongoing in superconducting linac

Accelerator Overview (47 mA)

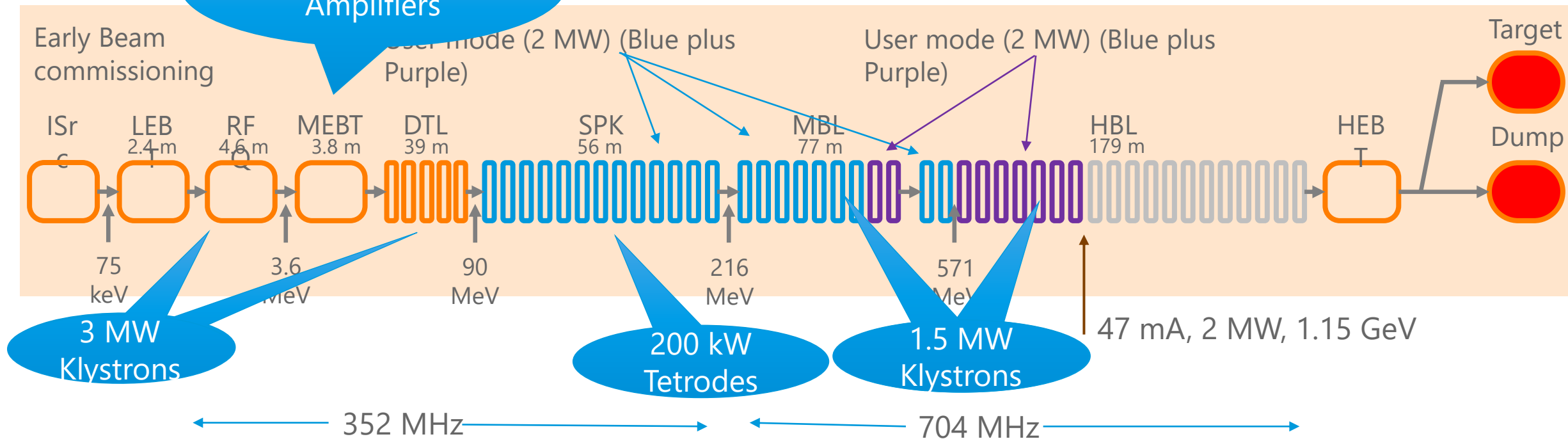


Key parameters:

Average Beam Power: 5 MW
 Peak Beam Power: 125 MW
 Beam pulse width: 2.86 ms
 Beam energy: 2 GeV
 Final Beam current: 62.5 mA peak
 Repetition rate: 14 Hz

Linac Section	Number of systems	Output Power	Amplifier technology
RFQ and DTL	6	3 MW	Klystron
MEBT	3	30 kW	SSPA
Spoke	26	400 kW	Tetrode*
Medium Beta	36	1.5 MW	Klystron
High Beta	84	1.5 MW	Klystron

*under review

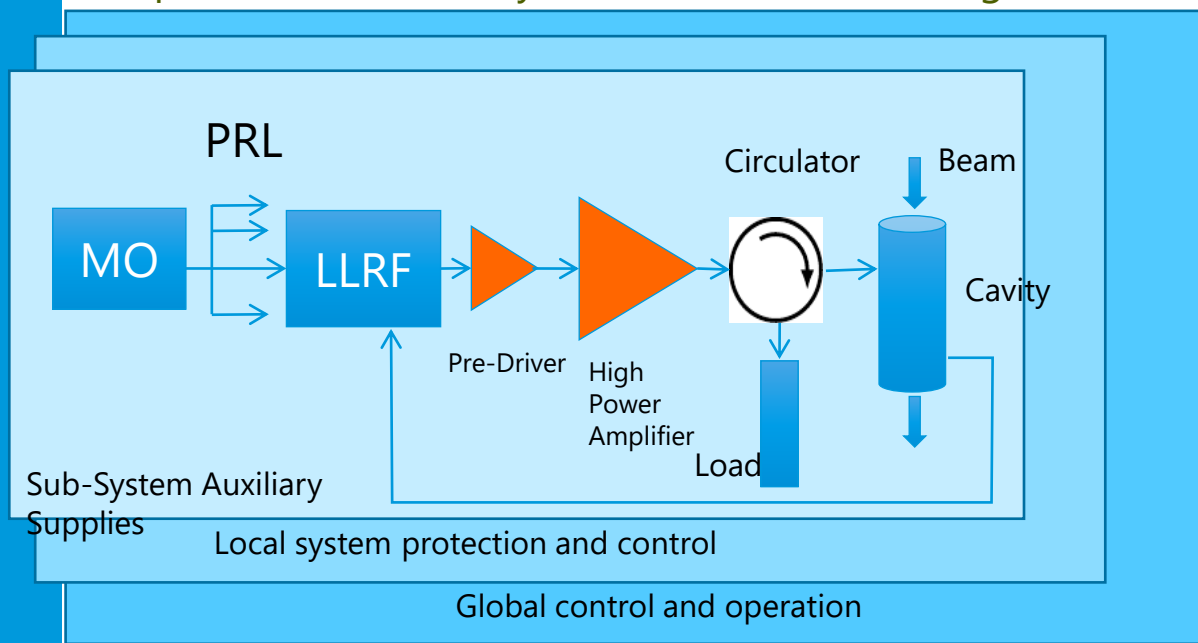


RF Systems Technical Scope Summary



RF Group is responsible for the design, procurement, installation and test of RF power stations from the RFQ to High Beta Budget is approx. 100 M EUR

- 155 Vertically integrated high power RF systems including > 400 racks, klystrons, low and high power amplifiers, low level RF control, interlock systems incl PLCs and FPGAs, auxiliary supplies, PSS and protection-sub systems.
- All RF distribution including > 6000 waveguide components, loads, circulators and controls.
- Approximately 21000 cables incl connectors for the RF system components with approximately 40% procured and installed by RF with the remainder from Infra
- Master oscillator, phase reference line including amplifiers, phase compensation, gas and temperature control with tap points for all LLRF systems and for beam diagnostics.



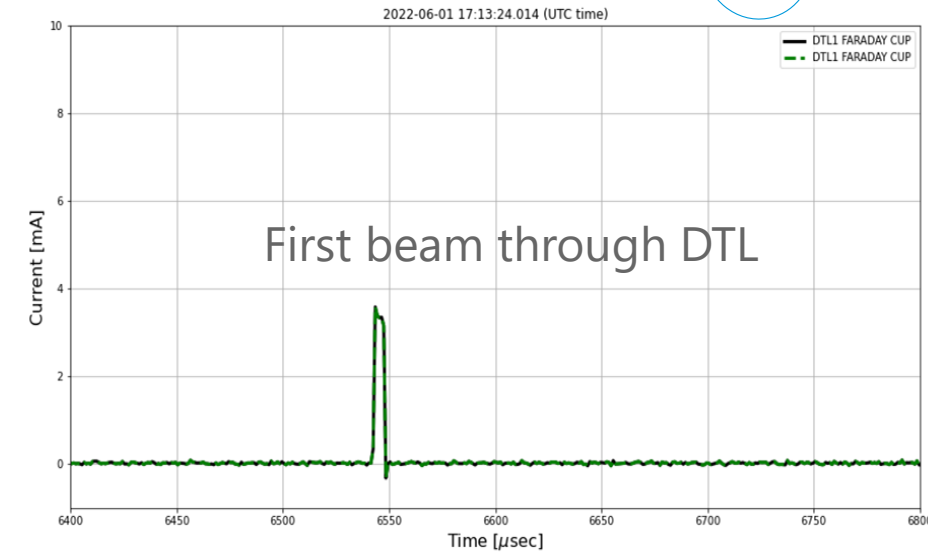
Typical High Level System

	Racks	Vertical integration	Amplifier	System commissioning
RFQ	3	1	1	1
MEBT	3+3	3	3	3
DTL	15	5	5	5
Spoke	52	26	-	26
MB	108	36	36	36
Totals	184	71	45	71
HB (p1)	60	20	20	20
HB (p2)	72	24 (later)	24	24
HB (p3)	120	40 (later)	40	40
5 MW	436	155	129	155

RF Systems in Normal Conducting Linac (NCL)

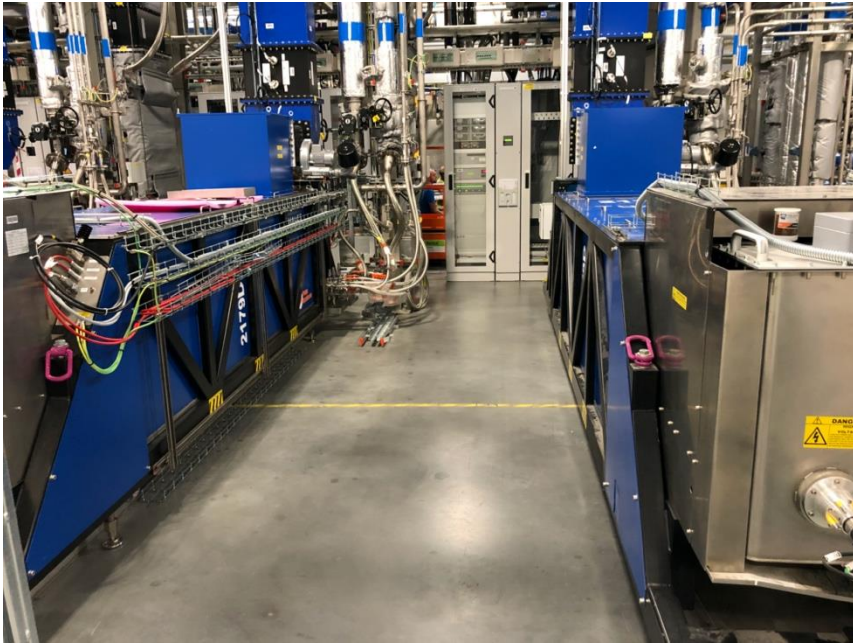


RFQ, 3 MEBT and 5 DTL RF systems installed and high power tested.



3 MW, 352 MHz Klystrons
for the RFQ and DTL 1

NCL RF system – RFQ, Bunchers and DTL in operation



DTL 3-4 klystrons



RFDS



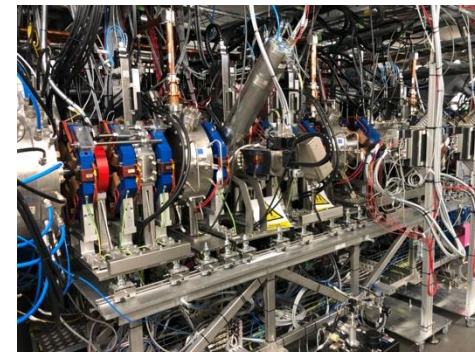
MEBT



Tunnel
connection
to RFQ



DTL 1



MEBT RF Systems

30 kW output

Frequency: 352 MHz Solid State Power Amplifiers

Consists of five hot-swappable RF modules combined

High Power Circulator and Load

Internal interlock system and state machine

Output line:

35 m, 1 5/8" coaxial line incl couplers and tuning



Spoke Systems

Amplification to 400 kW
Frequency: 352 MHz

26 Tetrode based amplifiers by combining two 200 kW Tetrodes.
LLRF, Interlocks, waveguides, loads and circulators etc.



Medium and High Beta

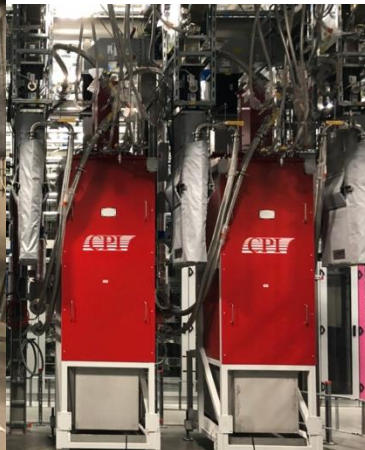


Amplification to 1.5 MW

Frequency: 704 MHz

Main components:

- Klystron and associated supplies for filament, solenoid and ion pumps
- Solid state drivers
- Interlock systems based on PLC and FPGAs
- Waveguide distribution incl. bends, directional couplers, bellows
- High power circulators and loads
- Arc detection
- Oil and desiccators



WP8 Components (Selection)

- Waveguide and Rigid Coaxial Systems
 - Waveguide (full/half height WR2300, WR1150)
 - Tapers, Magic T, Bellows
 - Directional couplers
 - Loads and circulators
 - Rigid coax system

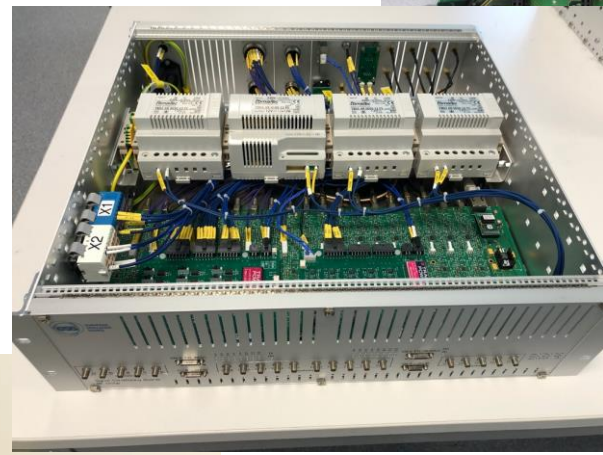


Typical In-House Design and Production

- RF electronics
 - Modulator split box
 - Cable testers
 - Split boxes
 - Patch panels
 - Directional couplers
 - ...



Fast RF switches



Signal Conditioning



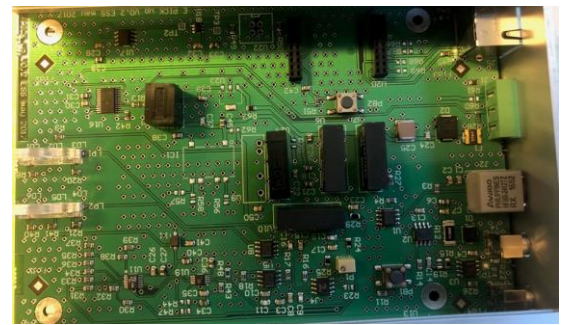
Interlock System



PSS switches



Electron pickup



Arc Detection

ESS Design: Drawing interest from other accelerator facilities.

Investigating how ESS can support including possibility of technology transfer, licencing, in house production etc.



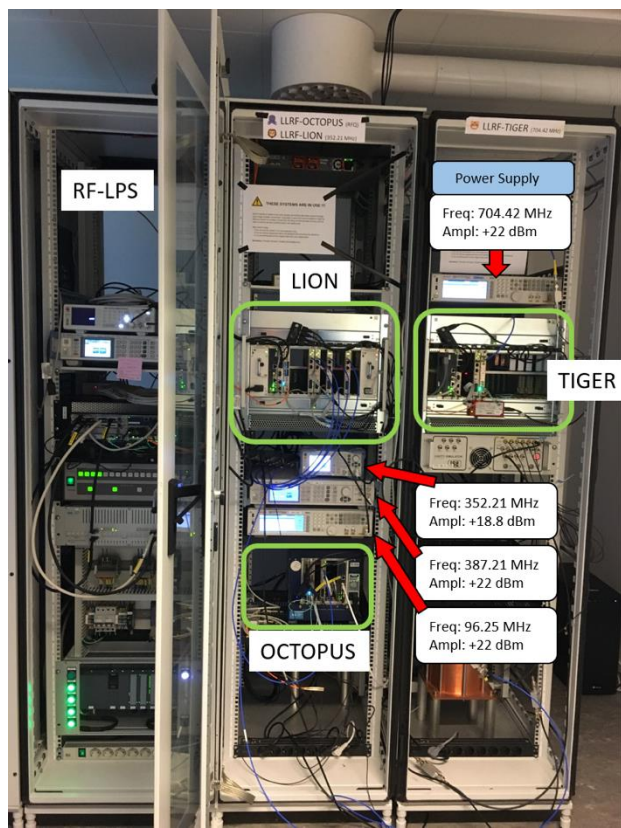
Low Level RF (LLRF)



System	First 10us (pk)		Rest of pulse (rms)	
	Amplitude	Phase	Amplitude	Phase
NCL	$\pm 1.0\%$	$\pm 1.0^\circ$	$\pm 0.2\%$	$\pm 0.2^\circ$
SCL	$\pm 0.5\%$	$\pm 0.5^\circ$	$\pm 0.1\%$	$\pm 0.1^\circ$



Master Oscillator

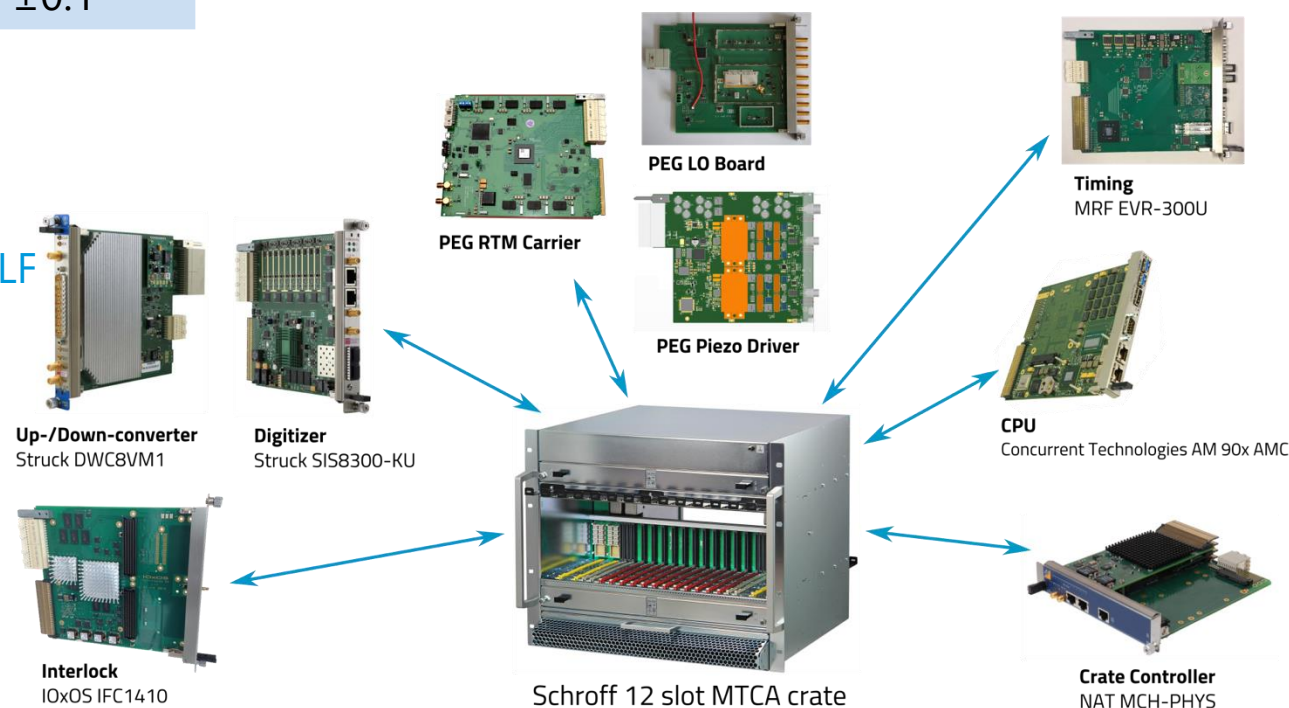


LLRF to correct for:

- Modulator HV ripple
- Beam current variation
- Lorentz force detuning (LF)
- Passband modes
- Microphonics
- Nonlinearities
- Noise

Development and demo systems:

- Running on nc cavities
- Allows test and debug prior to deployment



Cavity Simulator



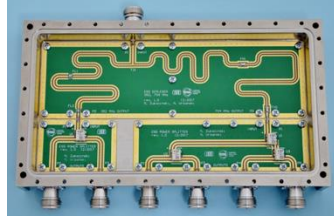
PRL and MO

Gas filled, temperature controlled, phase compensated rigid coax line running along the length of the tunnel

Two lines installed:

Each line carries both 352 and 704 MHz.

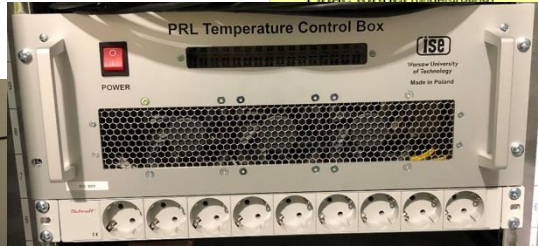
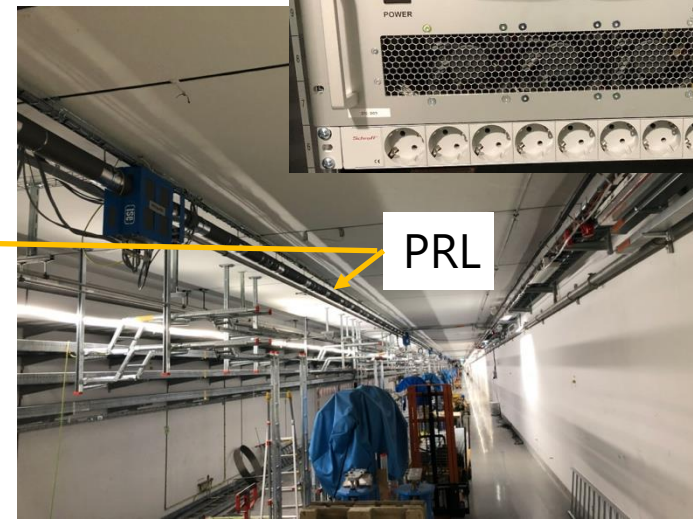
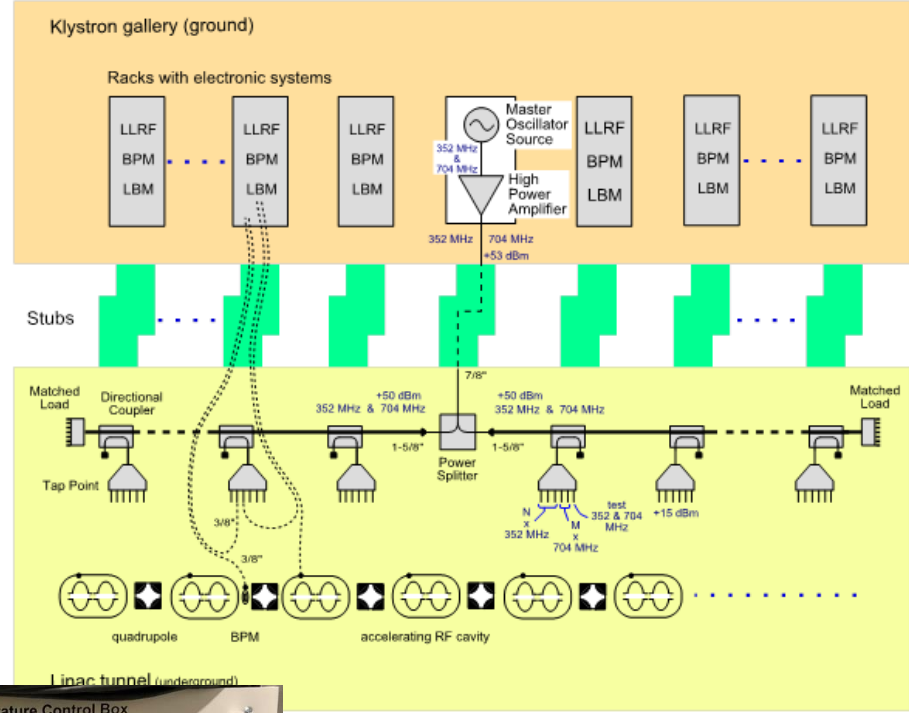
Carriers are phase compensated to ensure both frequencies are phase locked



58 tap points on coaxial rigid line



PRL heater and temperature control



Master Oscillator and MO distribution



RF System: Test-benches and system validation

- Prototyping, production and soldering areas
- Variety of test benches for hardware and interlock validation.
- Soldering equipment
- Test and measurement
- Tooling and lab consumables



Lab Overview



Test Stations



Soldering and Production

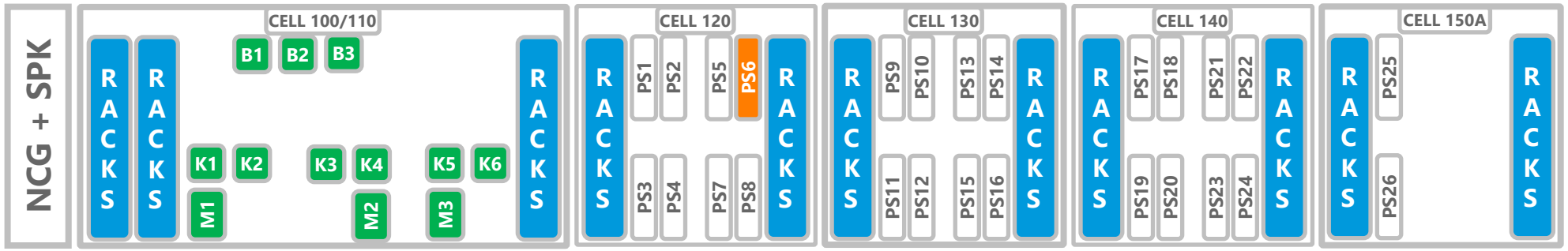


G02 – Status of RF Systems



Ready for Beam on Target (RBOT) Baseline

- # Installation on-going
- # Installation complete ready for test
- # Low Power Tested
- # High Power Tested



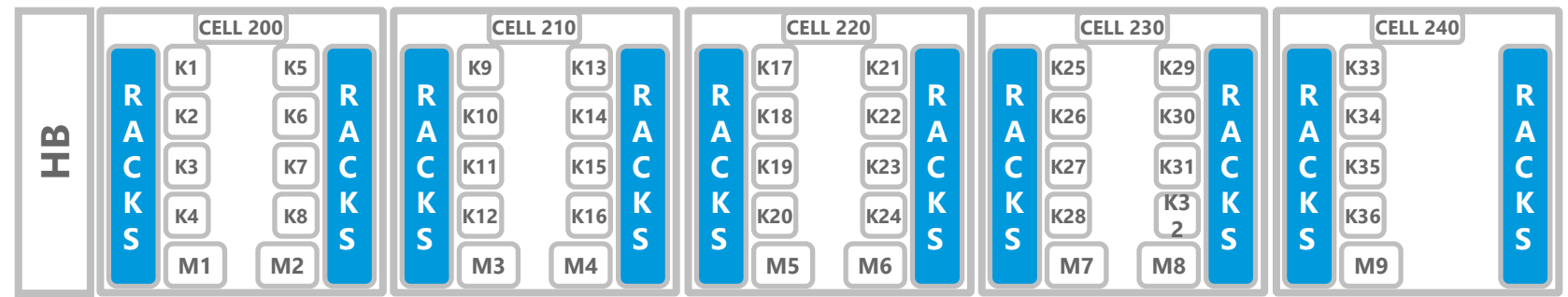
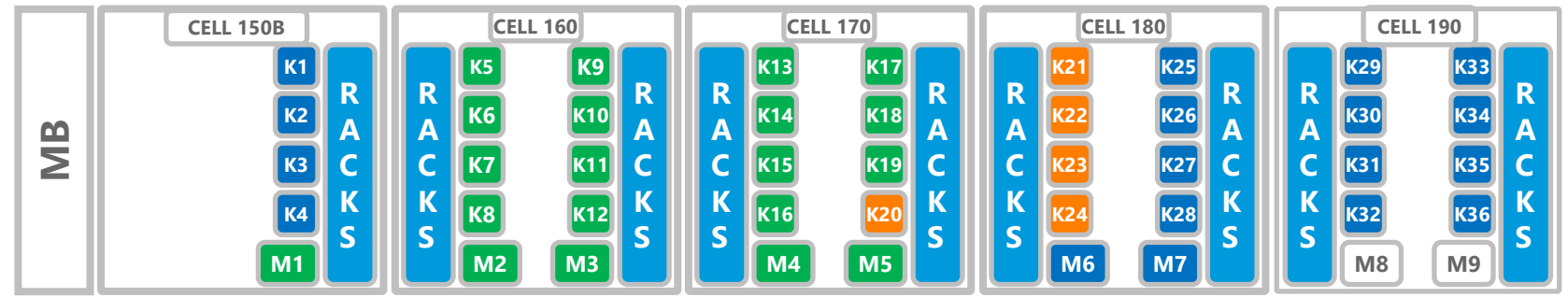
NCL: Klystron@3 MW

Bunchers: SSPA@30 kW

SPK: Tetrodes@400 kW

MB: Klystron@1.5 MW

HB: Klystron@1.5 MW



352.21 MHz

704.42 MHz

704.42 MHz



Competence and capability needs from industry

RF and Electronic Design

- PCB production and assembly
- Design and Build-to-Print
- High and low power amplifier components

Test and Measurement

- Equipment
- Test and calibration services
- EMC compliance testing

Electronic Component and System Assembly

Waveguide and Coax component manufacture

Component and system supply

- Spares
- Consumables
- Obsolescence management

Machining, welding and cooling systems

Cable assembly manufacture



Up coming and Specific Procurements including next Phase of 16 RF Stations.

- 3 MW Klystrons @352 MHz
- 1.5 MW klystrons @ 704 MHz

- New klystron prototype development: 500 kW, 352 MHz
 - Potential need for 26 systems plus spares

- Calibration service for T&M incl Spectrum Analysers, Vector Network Analysers, Oscilloscopes, RF power measurement, RF leakage monitoring
- T&M replacement and repair

- Electronic components, RF components and assembly material

- Klystron gun tank high voltage insulation oil
- Consumables such as filters and desiccators.
- Spares, repair and replacement

- Upcoming spares procurement includes waveguide components
- Cabling and Connectors

Maybe we can also help you?

Could include:

- High power testing of components (examples: circulators, loads, waveguide components)
- Window and coupler conditioning?



Summary

155 complete RF systems (transmitters) are under construction
Average RF power to beam of 5 MW means installed peak power > 130 MW

Assembly and Installation of > 400 RF racks is underway
Component testing, tuning and high power testing are in progress

Although the majority of the larger construction procurements are complete there are new opportunities in:

- PCB assembly, population and packaging of electronic systems
- Supply of spare electronic and RF components
- Waveguide and rigid coax components
- T&M supply, service and calibration
- Solid State Amplifiers



Thank you for your attention
We look forward to working with you

