



EUROPEAN
SPALLATION
SOURCE



An Overview of the High Power Radio-Frequency Distribution System of the ESS

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University of
HUDDERSFIELD

THE AWARDS
WINNER
2011, 2012, 2013, 2015

THE AWARDS 2013
AWARD WINNER
UNIVERSITY OF THE YEAR



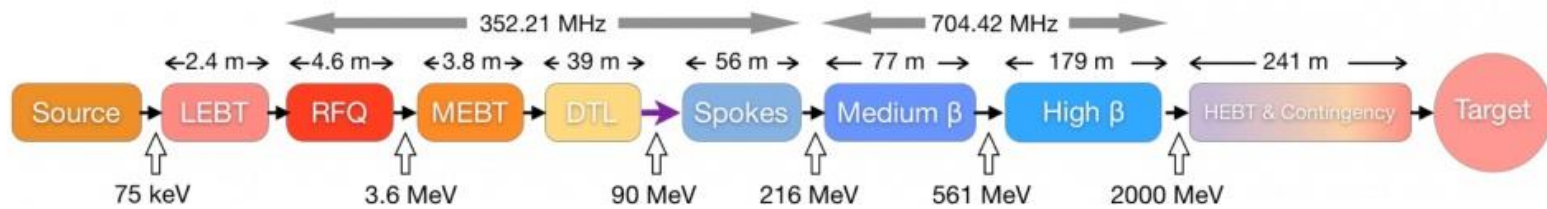
QS STARS
RATED FOR EXCELLENCE
2015

Athena SWAN
Bronze Award

Accelerator



Credit: ESS



Credit: T. Korhonen, ESS 2

Linac

- Power: average 5MW, peak 125MW
- RF Pulses to cavities: duration 3.5ms at a rate of 14Hz
- 146 superconducting cavities
- High beam availability target so:
 - accelerator should run, after re-tuning, even when multiple RF sources or cavities are inoperable
 - One RF source for each cavity
 - Dedicated waveguide run for each cavity

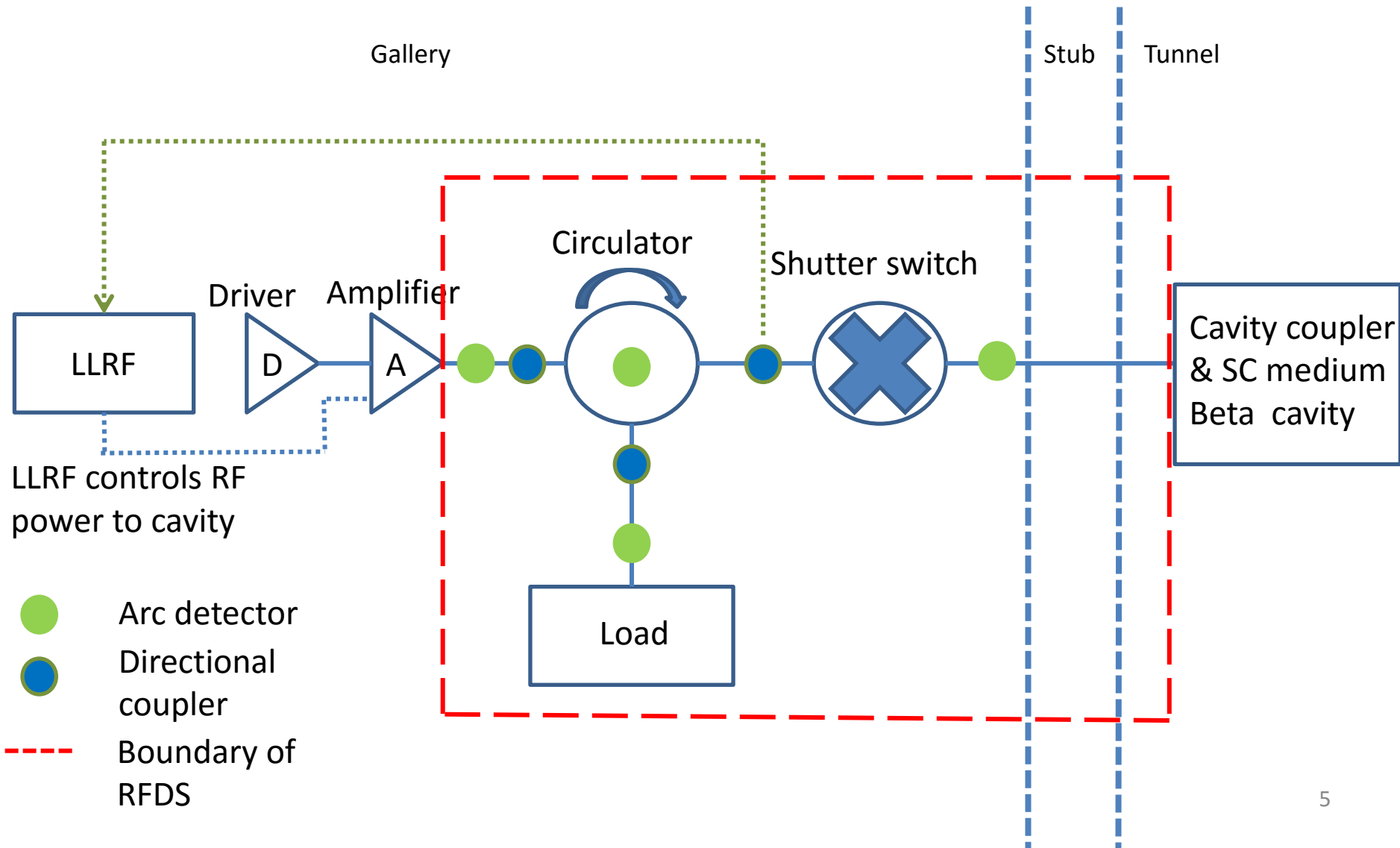
ESS

RF Subsystems

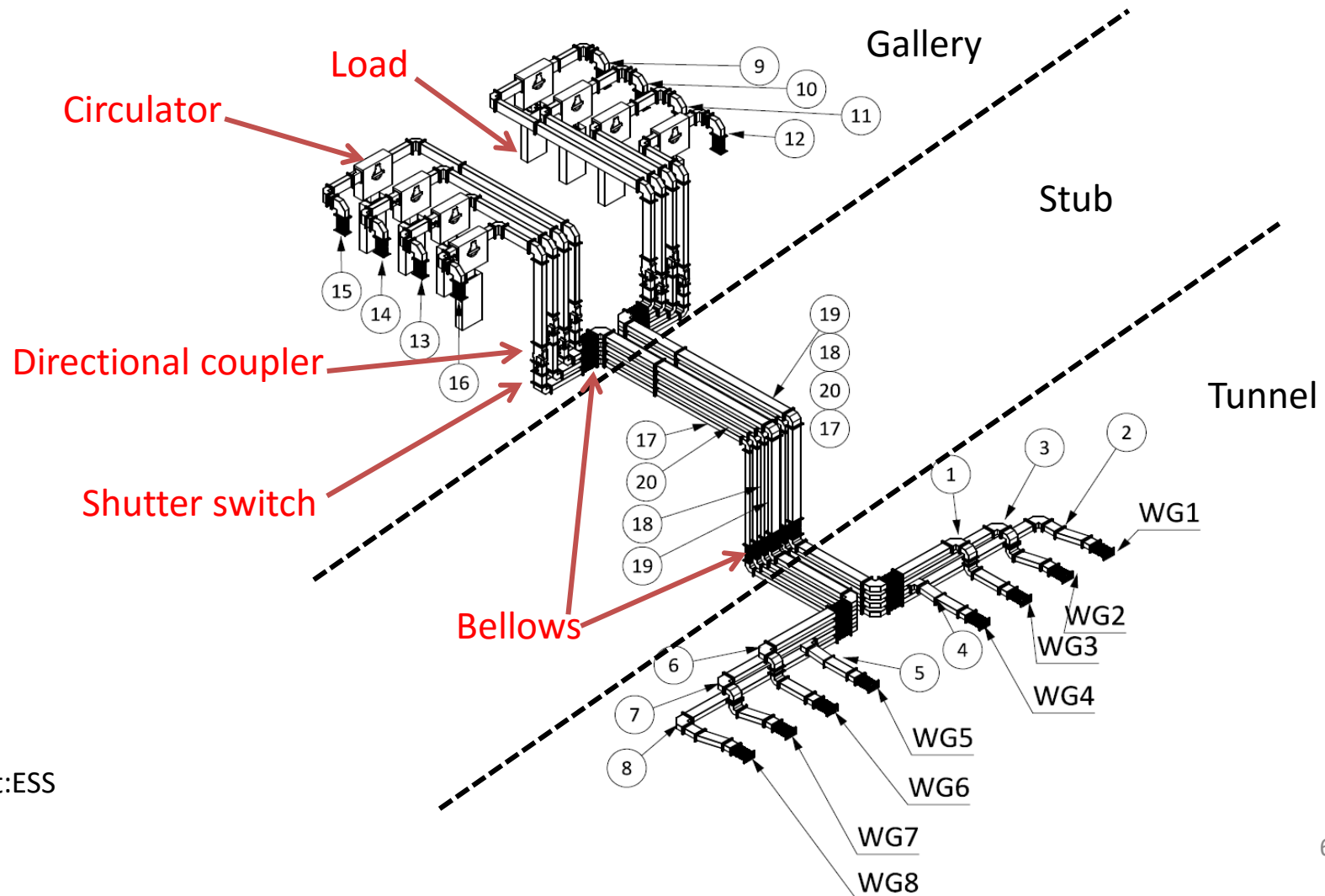


- **Power conversion subsystem:** Converts wall plug power into a form that the amplifiers can use.
- **Amplifier subsystem:** Amplifies a lower level RF signal to the power level needed for each cavity.
- **LLRF subsystem:** Regulates cavity tuning and the setting of amplitude and phase for the RF signals.
- **Distribution subsystem (RFDS):** Transports high power RF from the amplifiers to the cavity couplers.
- **Control subsystem:** Interlocks, controls, and interfaces to other systems

RFDS for Medium Beta Cavity



Typical Layout for Waveguide Runs



Credit:ESS

Approximate Numbers

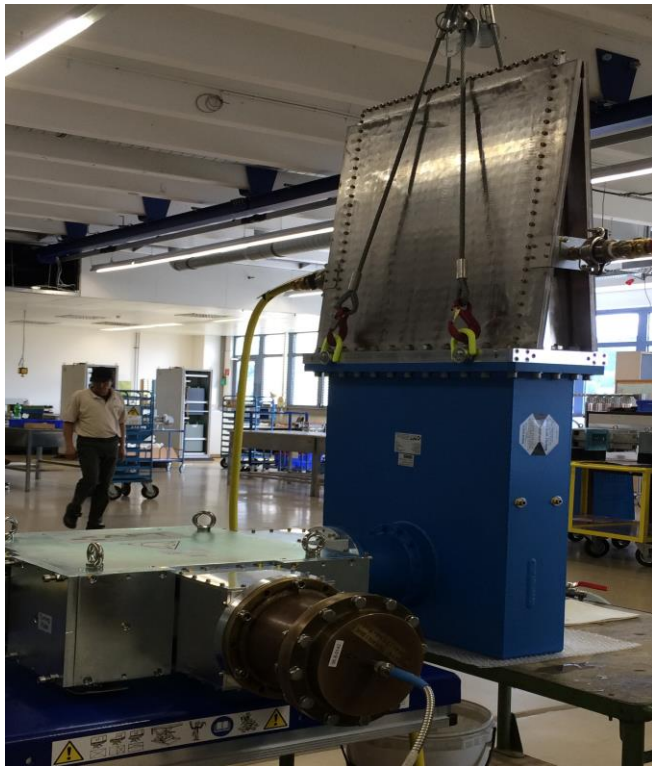
Component	Spoke Cavity	Elliptical Cavity
Waveguide	570m	2700m
H bends	130	480
E bends	106	720
Bellows	130	600
Directional couplers	78	360
Arc detectors	104	480
Circulators, loads & switches	26	120
Coax elbows	52	

Waveguides

- Air filled
- Rectangular (TE₁₀ mode)
- Sizes: WR1150 (704.42MHz) and half height WR2300 (352.21MHz)
- Aluminium (6061-T6 alloy): lighter, less expensive than copper, losses comparable to copper
- Aluminium skin depth:
 - 4.4 micro metre @ 350 MHz
 - 3.1 micro metre @ 700 MHz
- Internal surface finish: better than N6 standard:
 - i.e. 'Ra' better than 0.8 micro metre

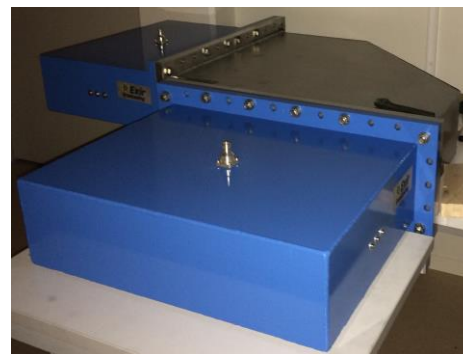
Prototype Components

Circulator loads being cooled with water at $\geq 50^{\circ}\text{C}$.



Credit: ESS / Freia Uppsala

Waveguide extends through the flanges

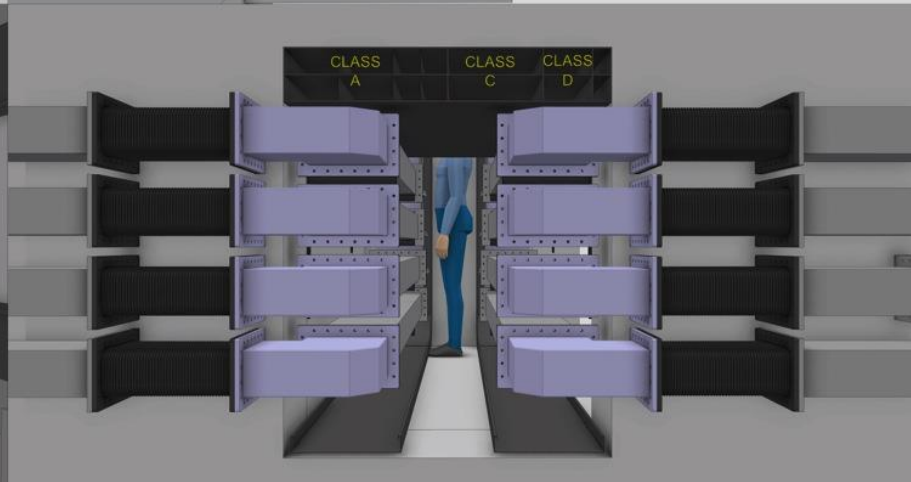
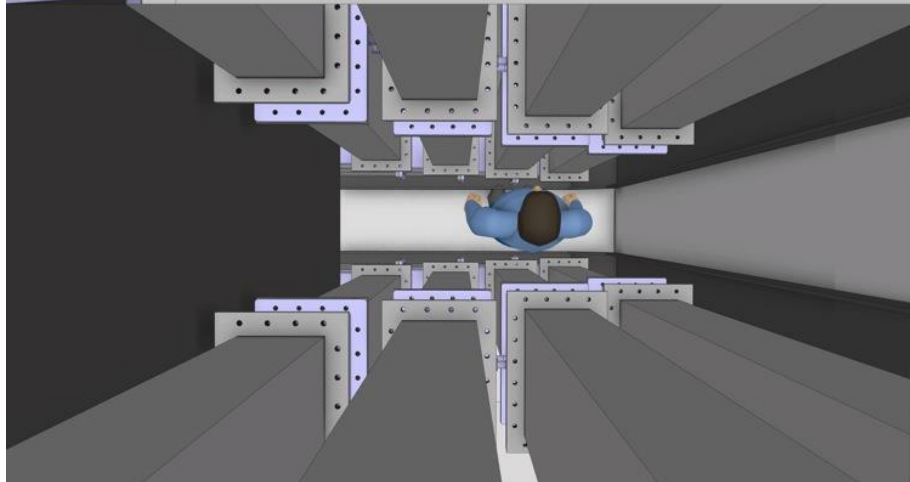
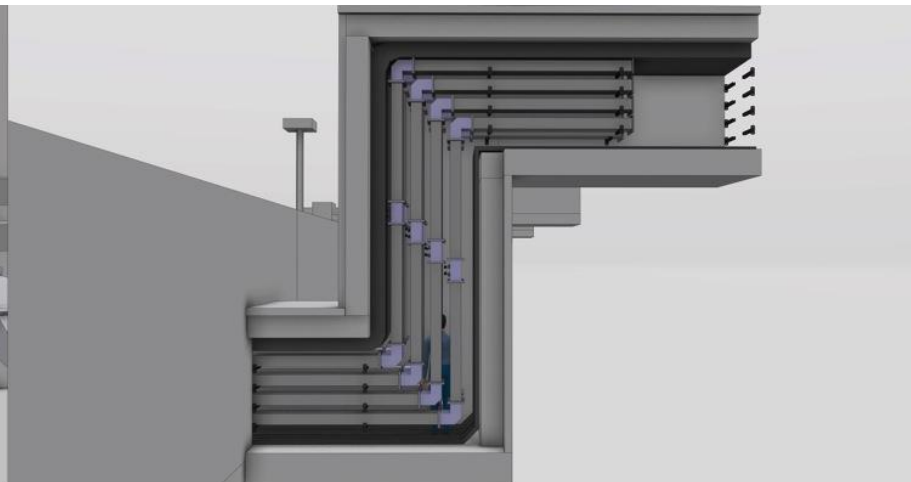
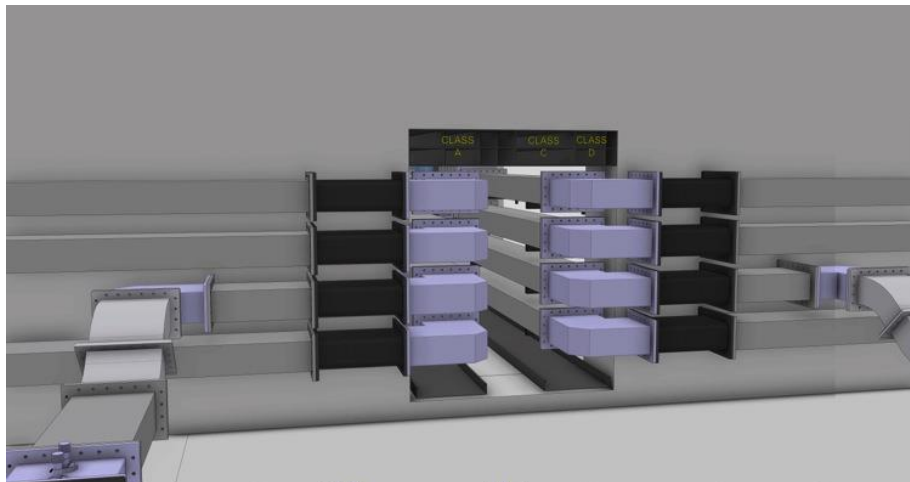


Credit:ESS

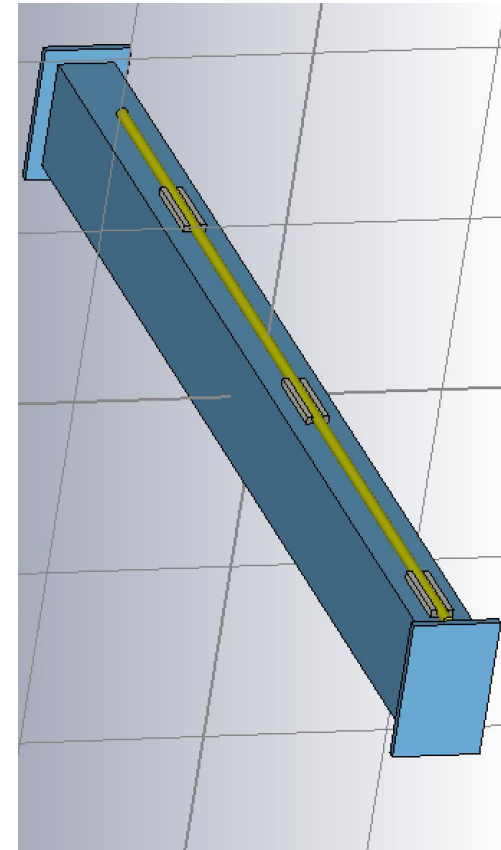
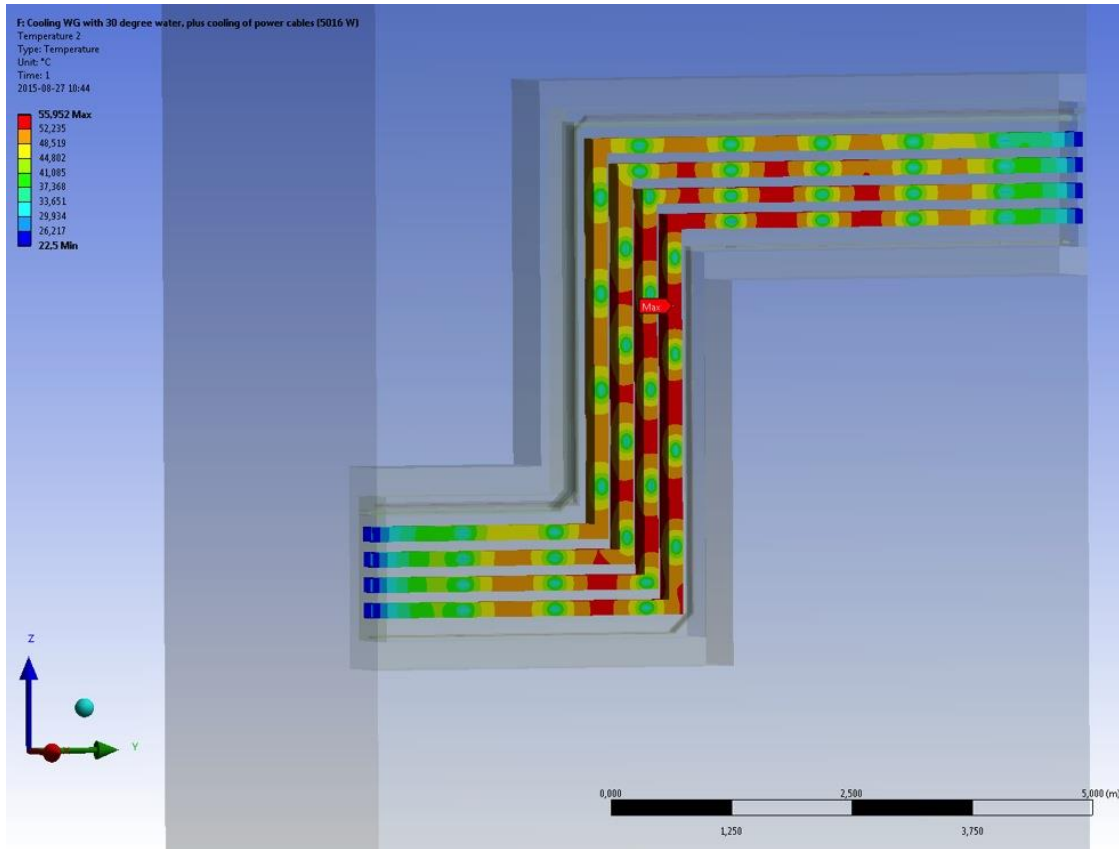
Waveguides

- Power dissipation can be $>4\text{kW}$ per stub (8 waveguides)
- To comply with local fire rules the stubs are sealed - so no free convection
- Without forced cooling, temperatures in stubs could reach $>200\text{C}$
- Waveguide cooling options considered include
 - External water cooling from tunnel
 - Internal forced air cooling

Stubs



Water Cooling in Stub



Credit:ESS

Water Cooling from Tunnel



- Brazing to aluminium
 - Could distort waveguide
 - Differential thermal expansion could cause cracks in braze
- Dependence on tunnel for water source
 - Access to tunnel for maintenance

Internal Air Cooling

- Concerns
 - High air flow rates
 - Need for air filtering etc.
 - Additional fixtures in waveguide walls for air inlet and air outlet
 - Potential for mixing of tunnel and gallery air
 - Relatively novel
- Possible adventitious benefit
 - High air flow rates may reduce likelihood of waveguide arcs

Arcs in Waveguides

- Concerns:
 - Arcs reduce power to cavity
 - Reflect power to RF source
 - Potentially damage waveguide walls and fixtures
- Causes:
 - Local field enhancement around ‘sharp’ items
 - Local heating from particulates
- Performance target:
 - Detect arc energies $\geq 5\text{J}$
 - Detect light levels $\leq 10\text{ lux}$
 - Detection time $< 10\text{ micro seconds at } 10\text{ lux}$

Constraints on RFDS in Tunnel

- No 'electronics' in tunnel
 - Access for maintenance
 - Possibility of activation
- No 'fibre optics' in tunnel
 - Access for maintenance
 - Possibility of degradation by radiation



- No waveguide arc detectors in tunnel. So between waveguide arc and arc detector there could be
 - 20m of waveguide
 - 6 waveguide bends
 - RF windows

Fibre-less Arc Detection

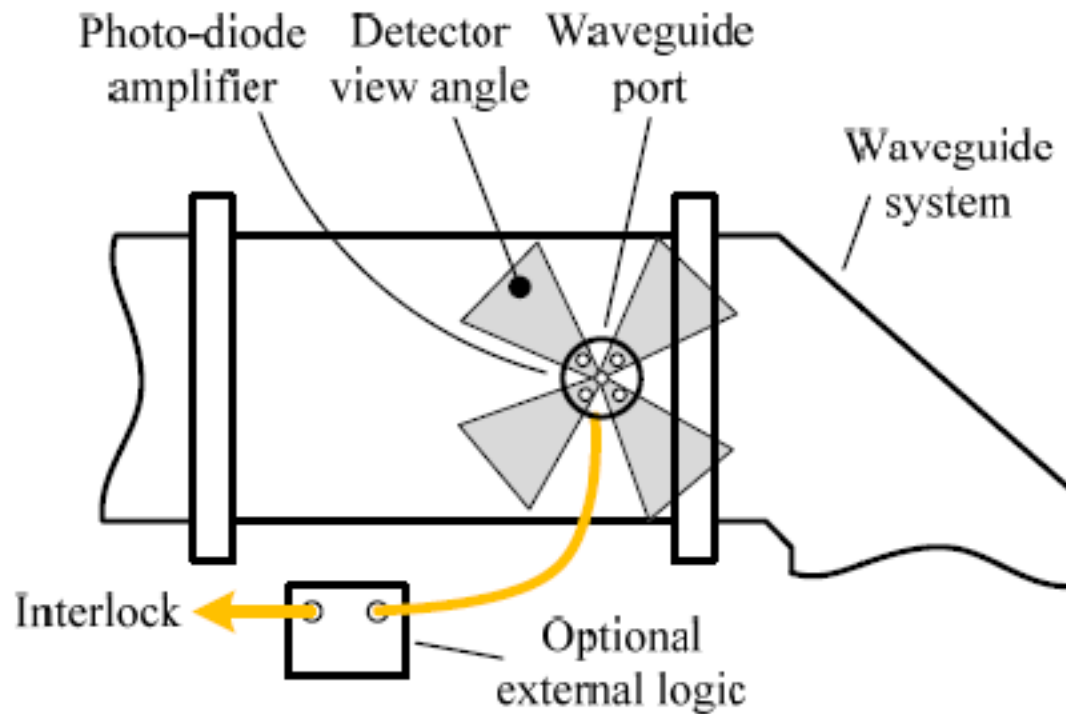
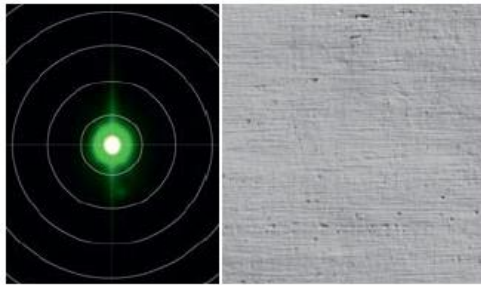


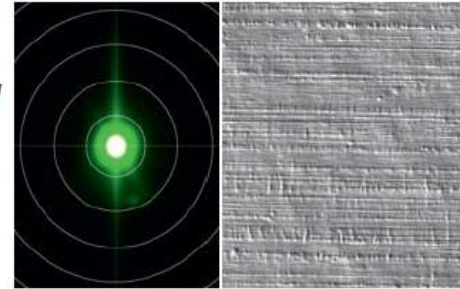
Figure 3: Fibre-less arc detector integration.

Aluminium Surface Finish



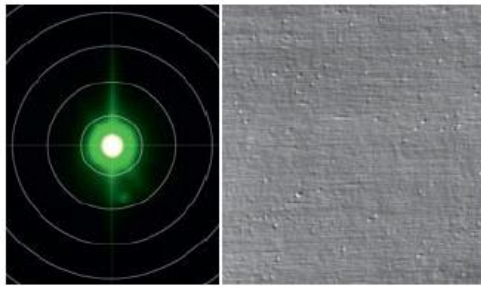
MIRO® 2 | 4200 GP

- > highgloss surface with low diffuseness < 5%, no preferential direction
- > optical mirror effect
- > high brightness



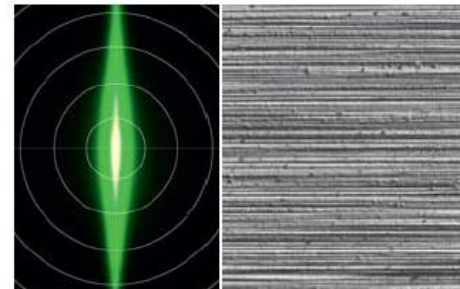
MIRO® 4 | 4400 GP

- > highgloss surface with low diffuseness < 12%, low preferential direction
- > optical mirror effect
- > high brightness



MIRO® 27 | 4270 GP

- > highgloss surface with low diffuseness < 6%, very low preferential direction
- > optical mirror effect
- > high brightness

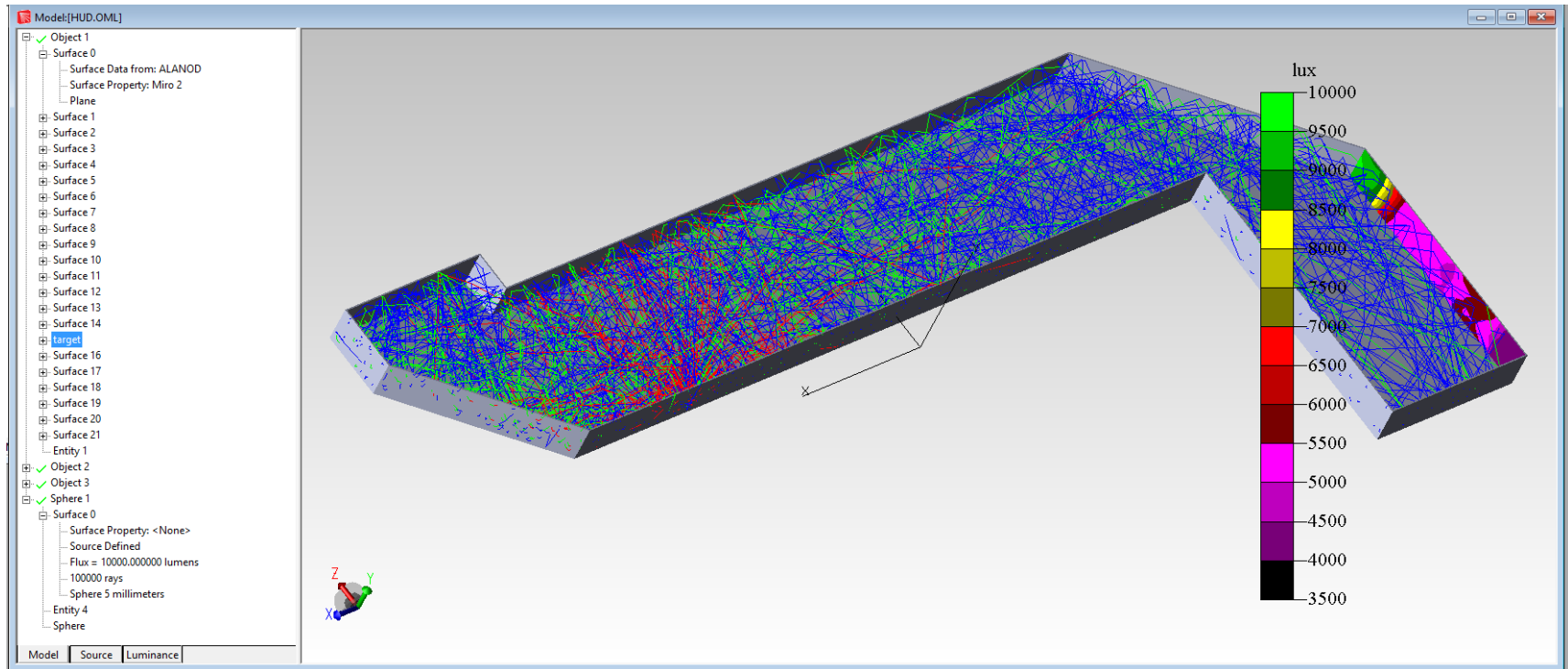


MIRO® 5 | 5011 GP

- > millfinish surface with strong preferential direction
- > high diffuse reflection value 80 - 90 %

Examples here are all N3 (Ra 0.1 micrometre) or better.
Waveguide specification is N6 (Ra 0.8 micrometre) or better.

Ray Simulation for Half Height WR2230



Credit: TracePro, Lambda Research

Aluminium Surface



- Low Roughness
 - Better RF propagation / less heat dissipation
 - Less attenuation of optical signals (from arcs)
 - Less resistance to air flow
- Higher Roughness
 - Better heat transfer to internal air flow?
 - Cheaper!
- Surface treatment
 - Reduces corrosion. Thickness <0.05 micrometres

Conclusions

- Technology for RF distribution is generally considered to be a mature technology
- The combination of constraints on the ESS has created some novel challenges for RF distribution
- Investigation of possible solutions continues in some areas