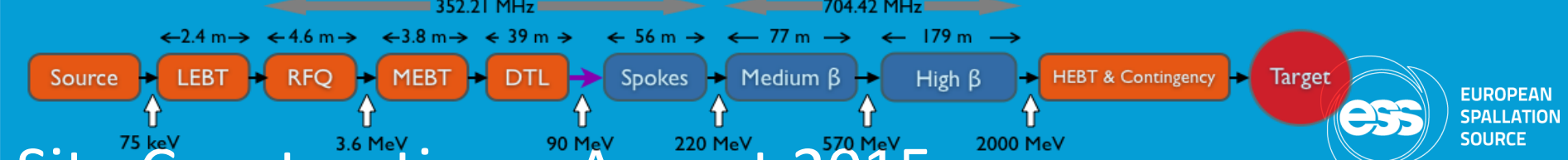
High Power RF Sources for the ESS RF Systems

Morten Jensen

www.europeanspallationsource.se
ESLS RF, 1 October 2015



Site Construction – August 2015

First bit of the RF Gallery

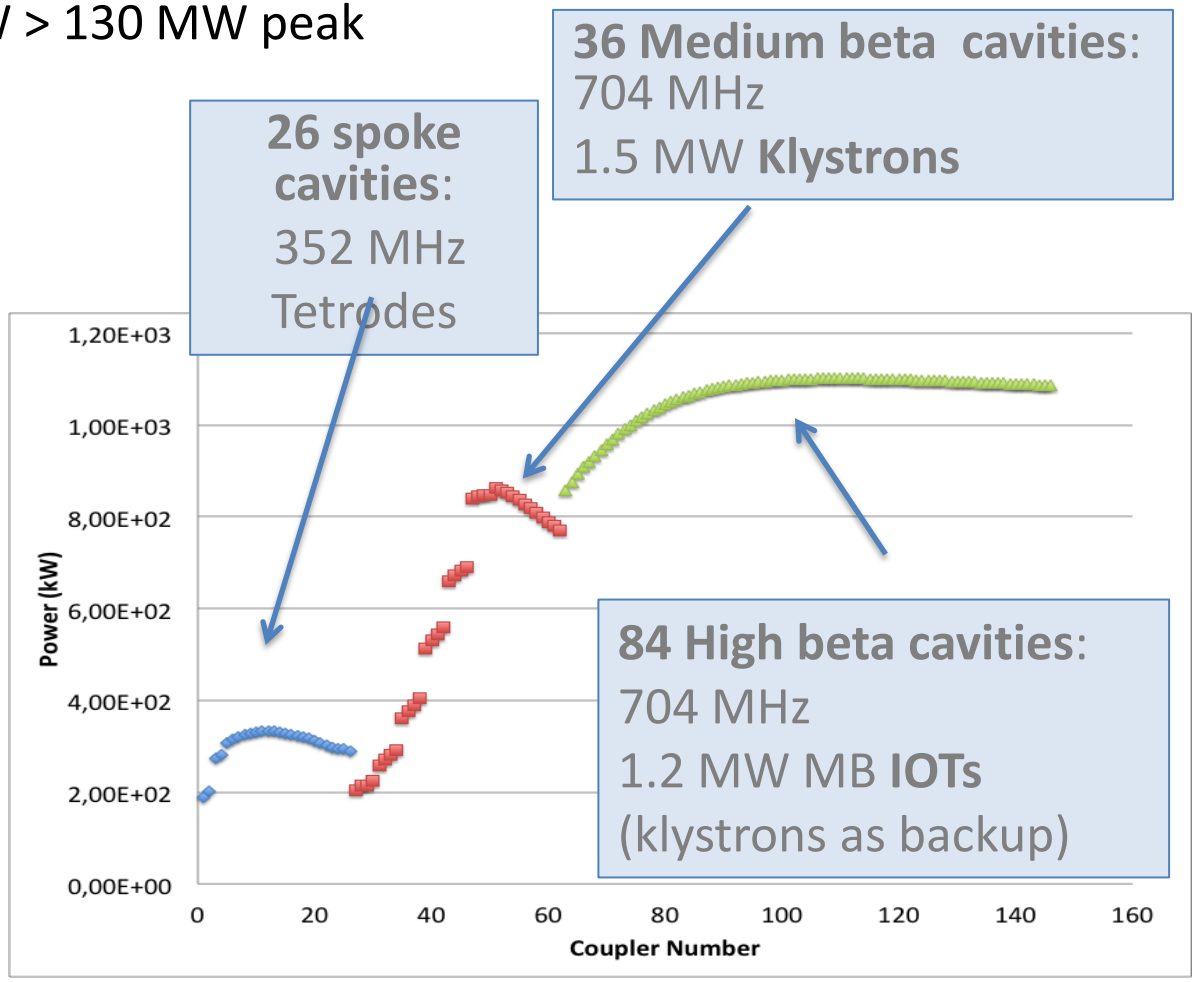
ESS accelerator power profile

Average beam power: 5 MW > 130 MW peak
Pulse repetition rate: 14 Hz
Beam pulse length: 2.86 ms

Normal-conducting Linac:

One RFQ and 5 DTL tanks
6 off 352 MHz klystrons
3 MW

3 Solid state amplifiers for bunchers
352 MHz, 30 kW



Normal conducting linac

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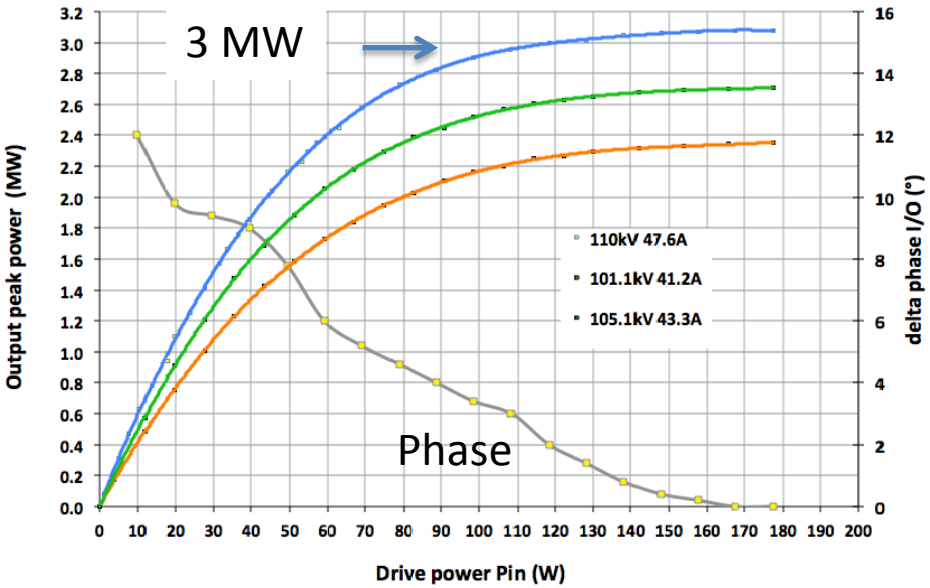
Output vs Voltage



Courtesy of Thales ED

Frequency	**352 MHz**
RF Power	3 MW peak
High voltage	to 115 kV
Current	to 50 A
Repetition Rate	14 Hz
Pulse width	3.5 ms

In-kind from ESS Bilbao

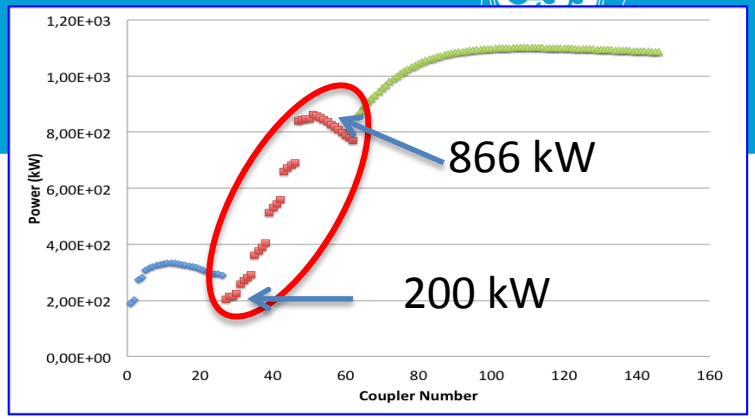
Thales TH2179

CPI VKP-8352A

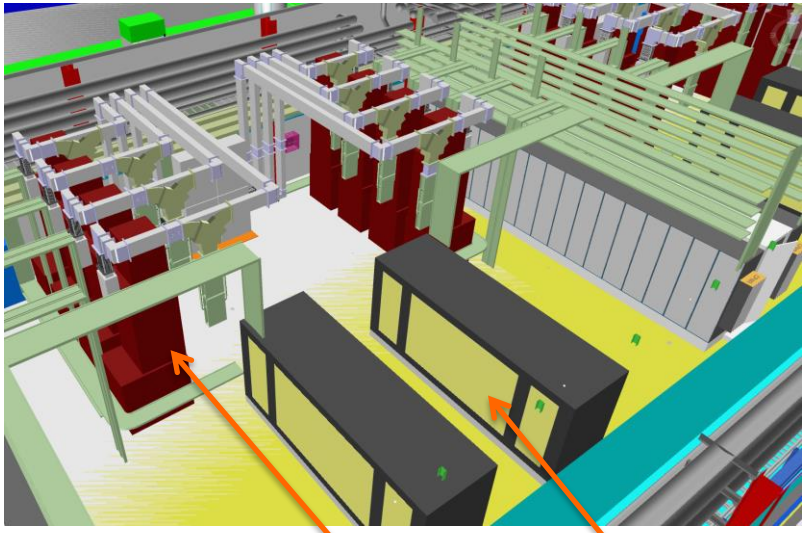
Two klystrons per modulator

Medium beta linac

Frequency	704 MHz
Power	1.5 MW peak
High voltage	to 115 kV
Current	To 25 A
Repetition Rate	14 Hz
Pulse width	3.5 ms



Vertical orientation to fit in the gallery



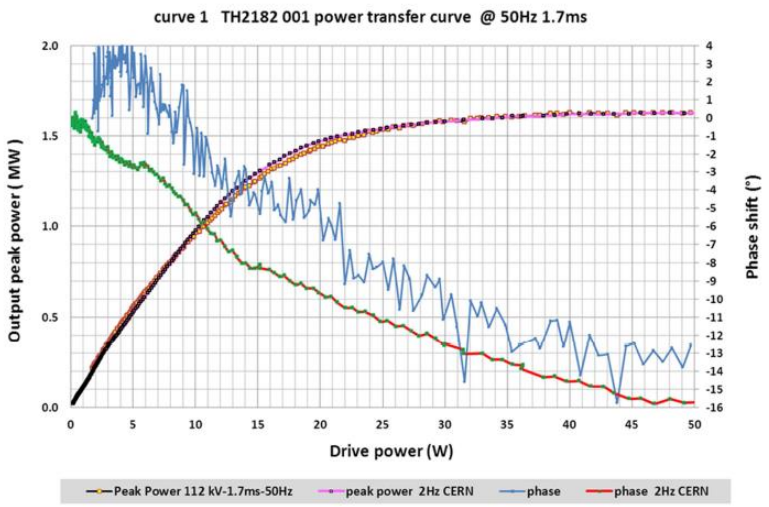
High Power Density: 12 MW of RF in approx. 10 x 13 m

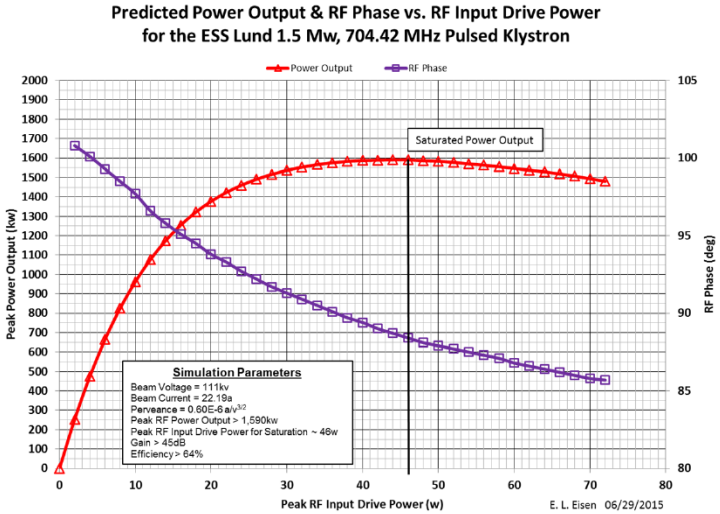
Four klystrons per modulator

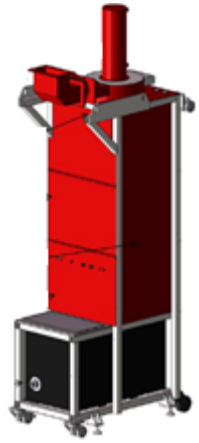
- **Three prototypes on order:** Thales, Toshiba and CPI
- Design reviews complete
- Delivery expected in **March** (Thales), **May** (Toshiba) and **July** (CPI) 2016

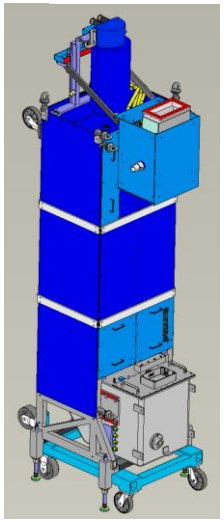
Courtesy of Chiara Marrelli

704 MHz klystron prototypes

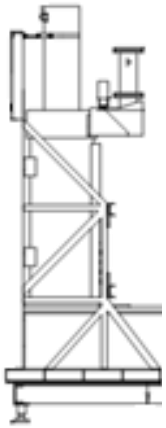


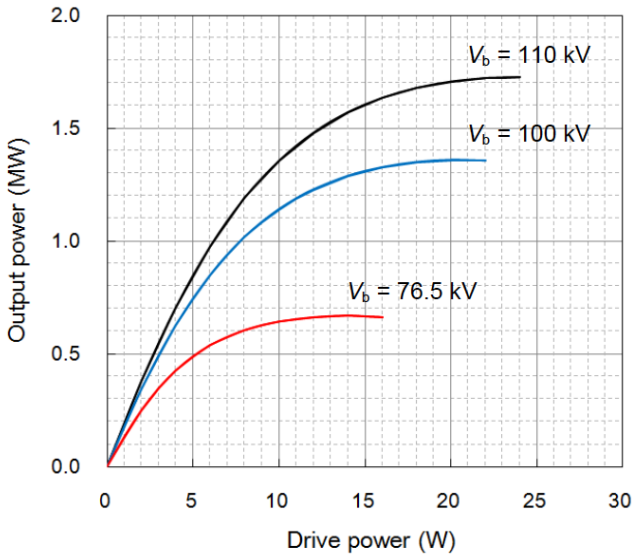






TH2180





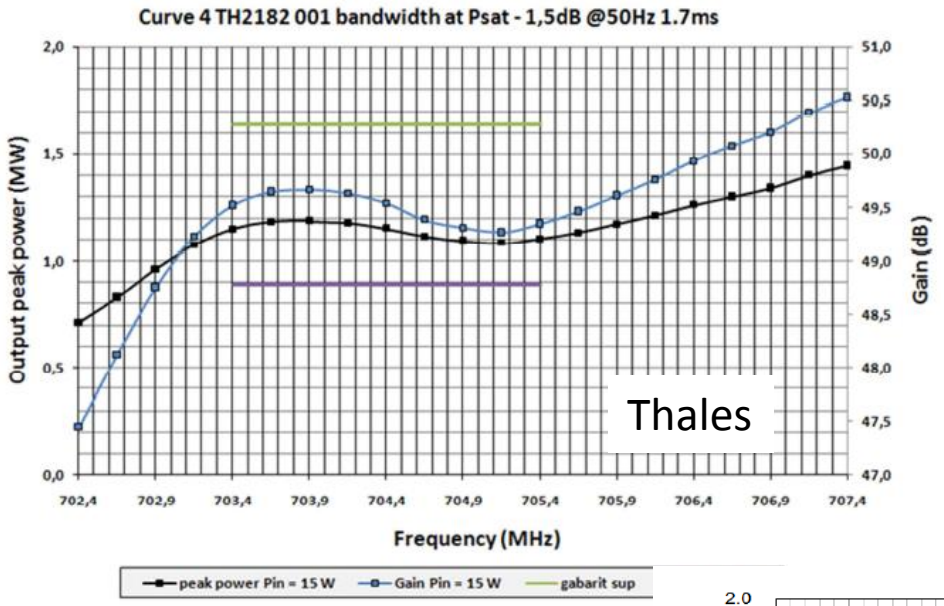
CPI VKP-8292A

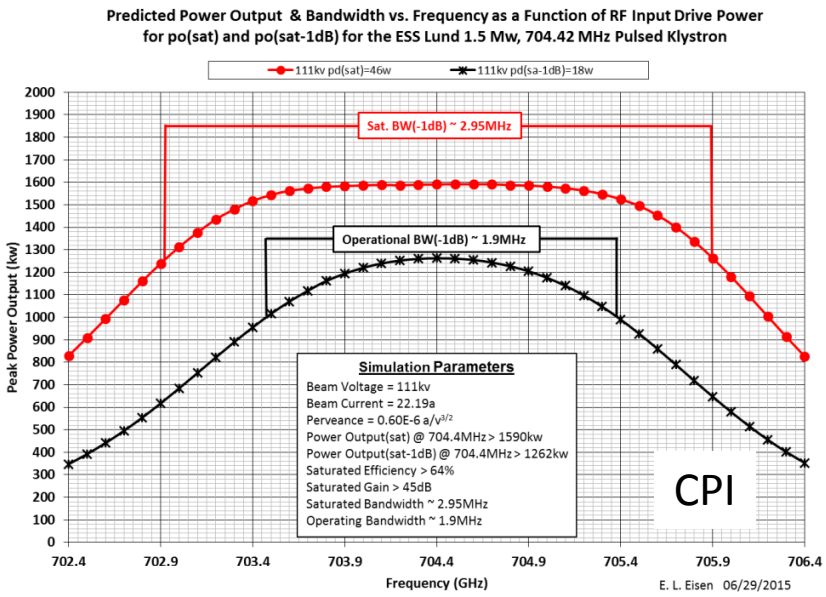
Toshiba klystron has higher gain

Toshiba E37504

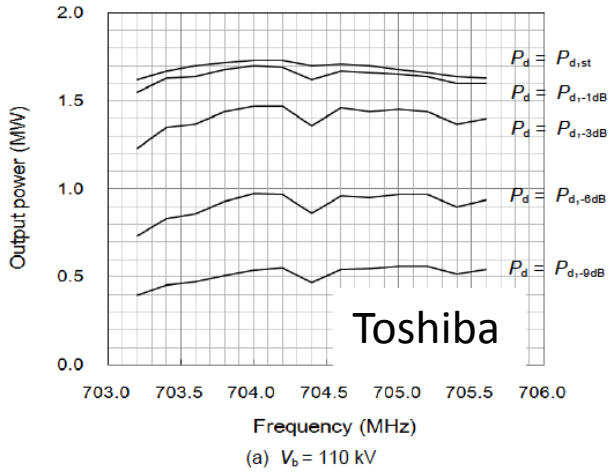
Courtesy of Chiara Marrelli

704 MHz klystron prototypes





Significantly different bandwidth response expected



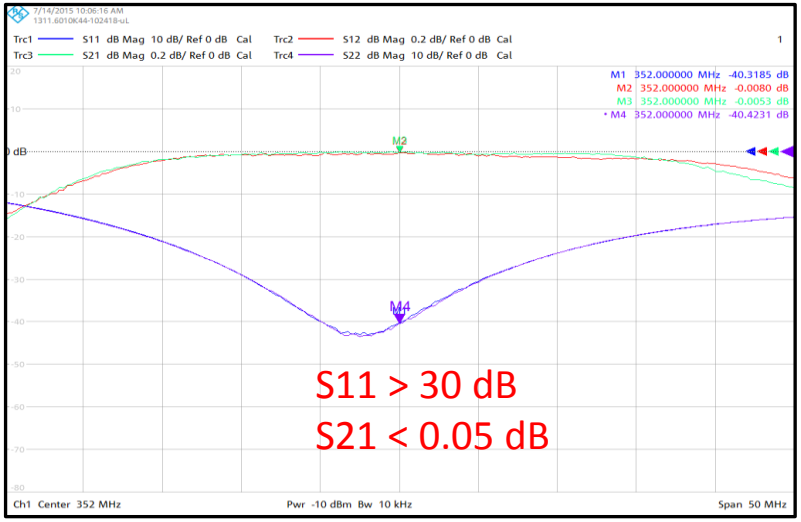
Courtesy of Chiara Marrelli

Distribution: Waveguide, coax, circulators and RF loads

ESS needs several kilometers of waveguide and thousands of elbows

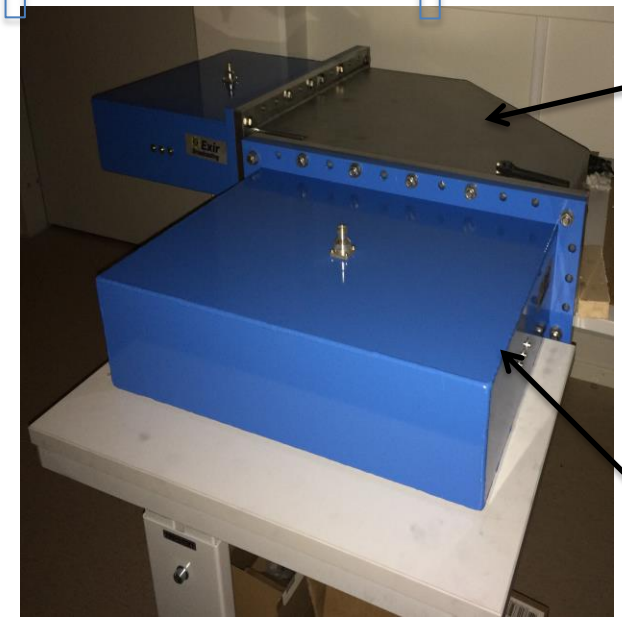
- Simple to design
- Detailed manufacturing drawings allow manufacture by variety of companies
- Potential of significant cost saving

First waveguide prototypes received from two companies



ESS Design

- Waveguide extends through flanges

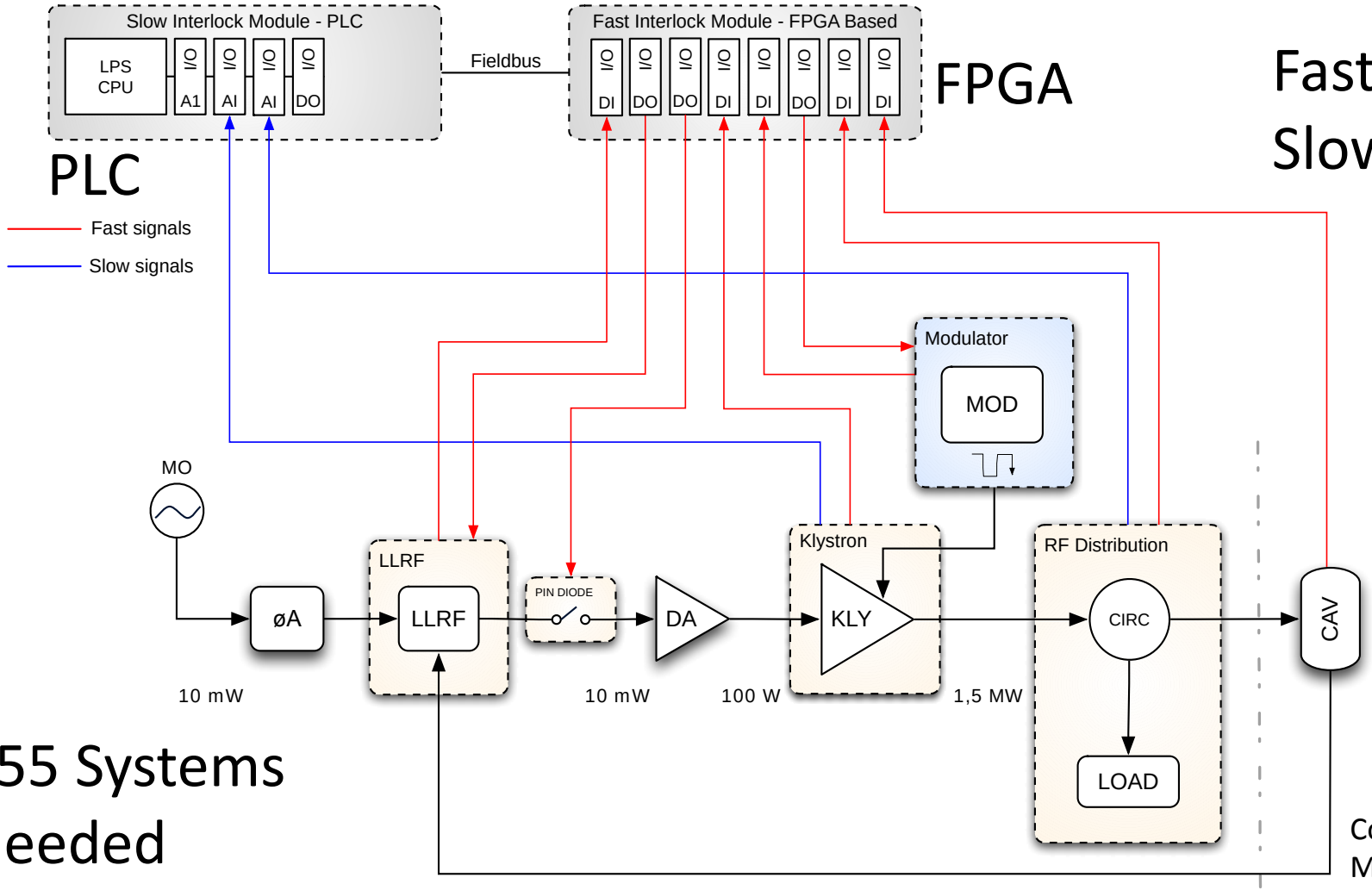


- Contracts signed for prototypes for 704 MHz circulators and loads
  - Circulators: AFT, FMT and MEGA
  - Loads: AFT, Thales and MEGA

Courtesy of R Yogi

Local Protection System - Interlocks

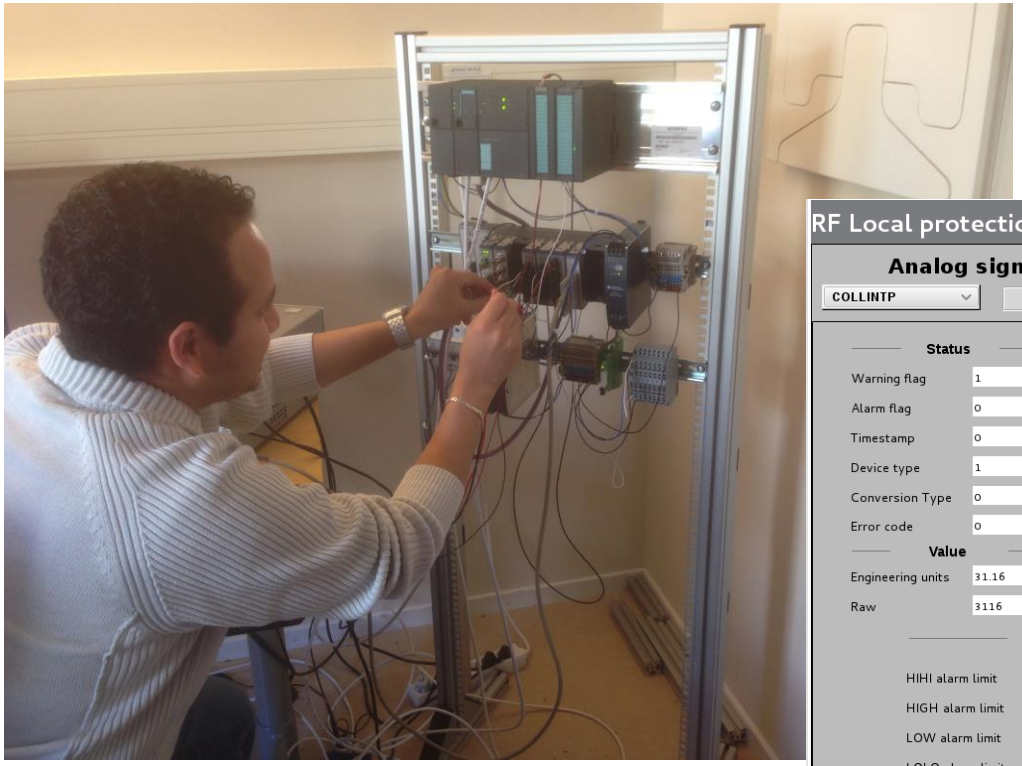
Typical RF Chain separating fast and slow interlocks

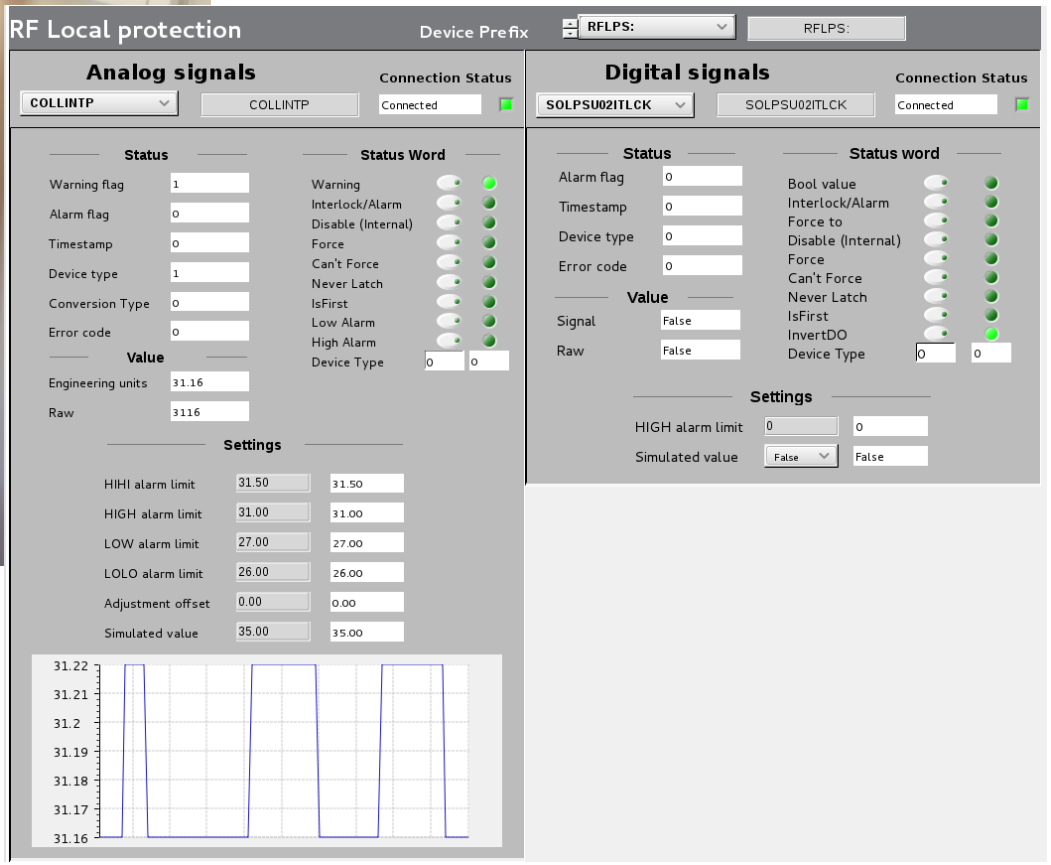


155 Systems Needed

Courtesy of Rafael Montano

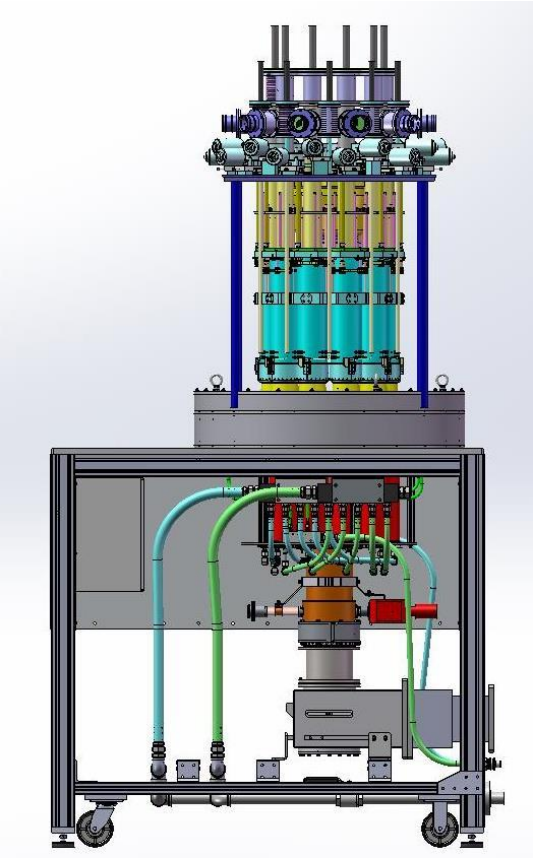
Local Protection System - Interlocks





Multi-Beam IOTs for ESS

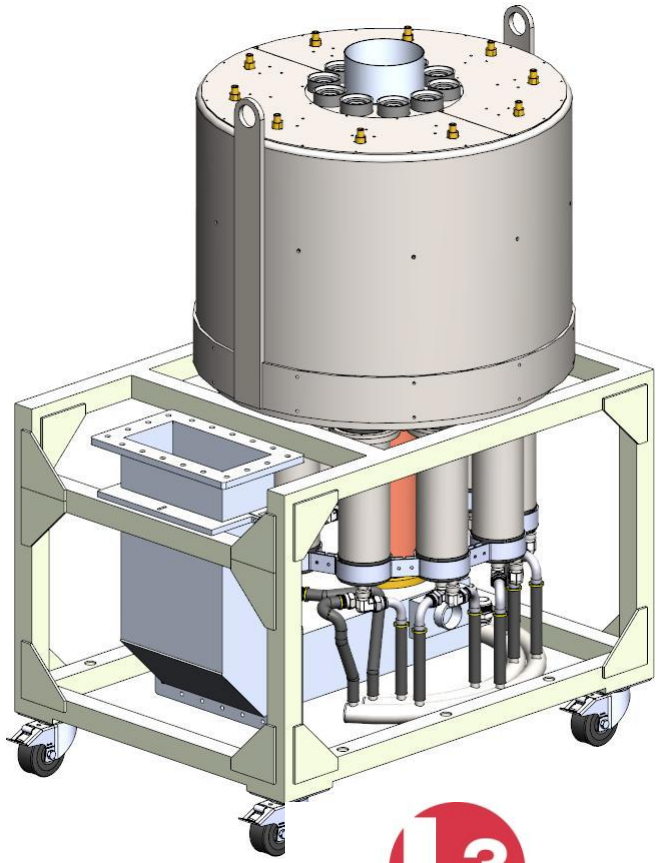
EUROPEAN SPALLATION SOURCE



Two prototypes on order for Delivery in 2016

L3 Design Review Complete

Thales/CPI Design Review in November



THALES

Communications & Power Industries
microwave power products division

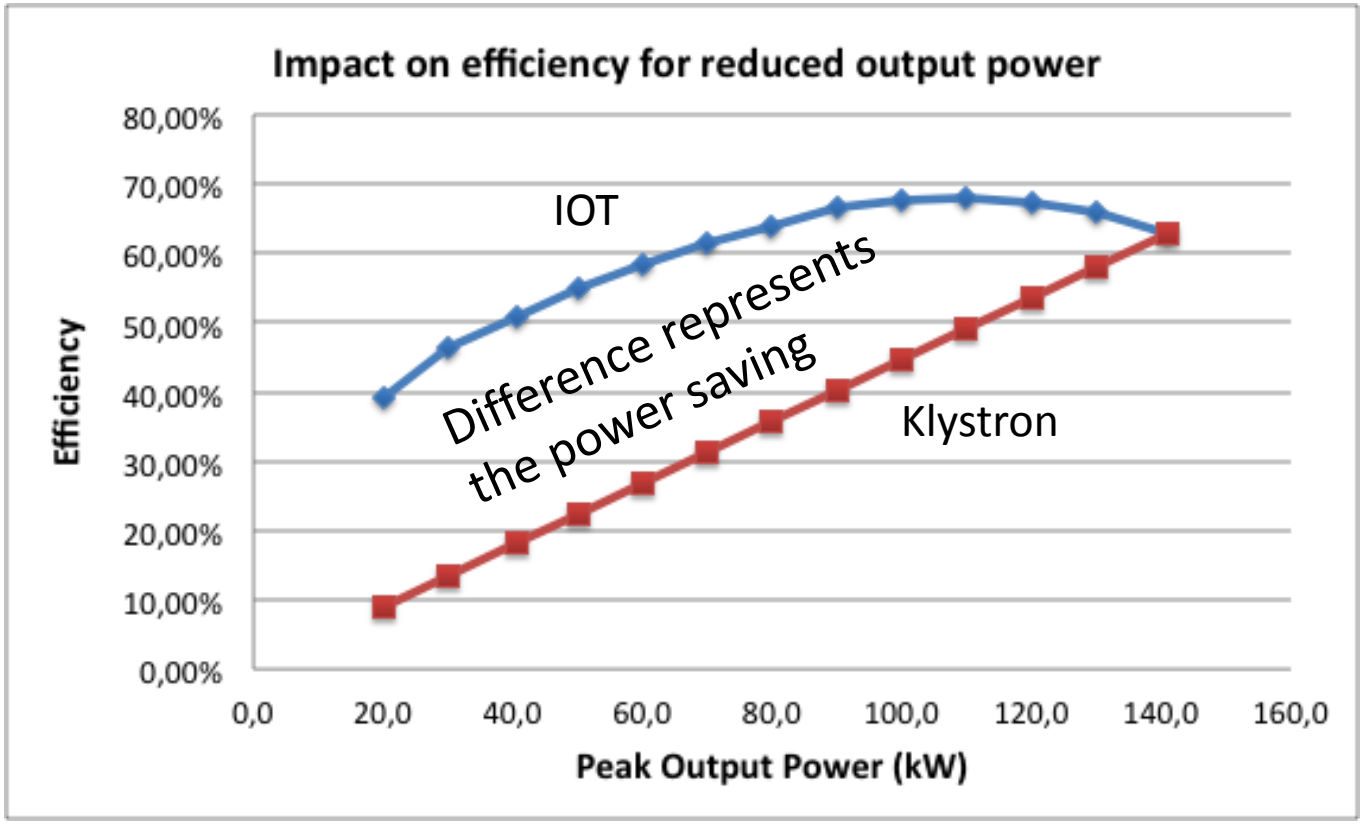
L3 communications

Specification

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	< 50 kV
Design Lifetime	> 50,000 hrs	

Target: Approval for ESS series production in 2017/18

Efficiency comparison of Klystrons and IOTs



- Klystron assumed to have same saturated efficiency as the IOT
- No optimisation of coupling, voltages, perveance for different power levels

IOT measurements courtesy of M. Boyle, L3

- Based on broadcast IOT L-4444
- System setup limited by drive power and beam voltage
- IOT setup for maximum gain (not efficiency) without breakdown
- No optimisation of coupling, grid voltages etc. for different power levels

IOT Design Summary

Both designs largely based on the broadcast design

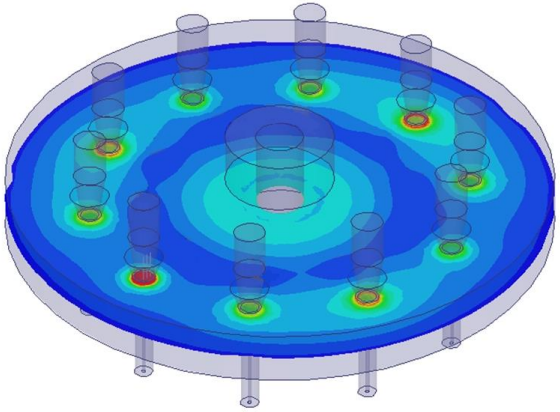
- 10 beams:
  - 10 electron guns placed in a circle
  - Separate grids and cathodes
- Single output cavity, with centre feed
- 10 individual collectors instead of a single large collector
- Coaxial output

Information is still very commercially sensitive

Output Cavity and DC Beam Studies Courtesy of L3 Communications

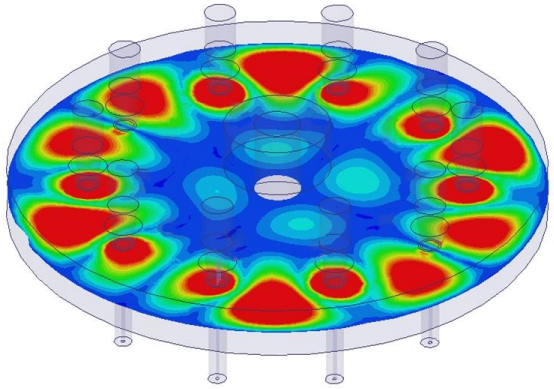
- Output cavity supports a large number of modes
- HFSS used to map modes near harmonics of the drive frequency

Fundamental



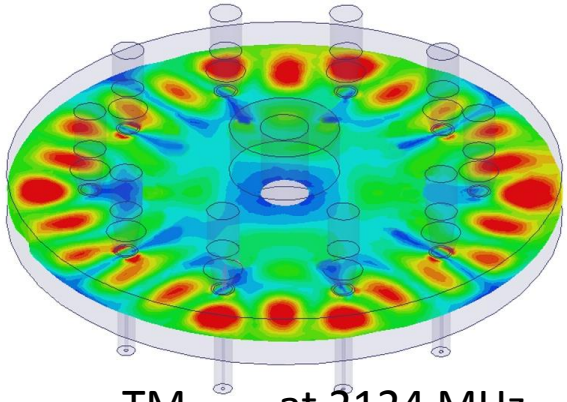
$TM_{1,0,0}$ at 704 MHz

Near Second Harmonic

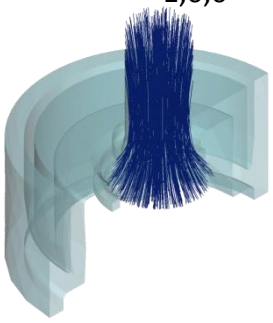


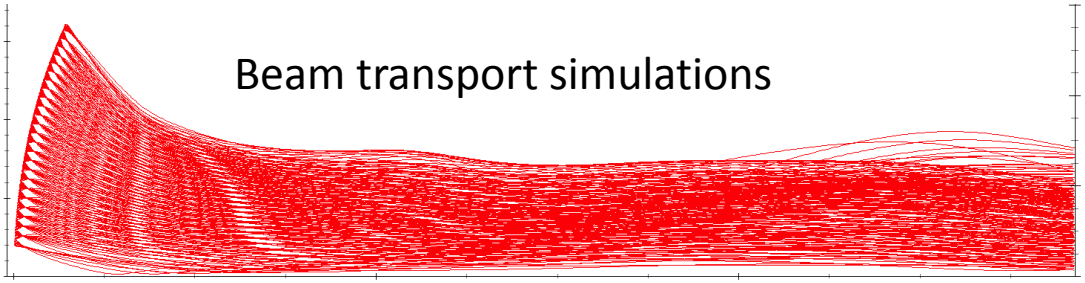
$TM_{1,16,0}$ at 1417 MHz

Near Third Harmonic



$TM_{1,24,0}$ at 2124 MHz

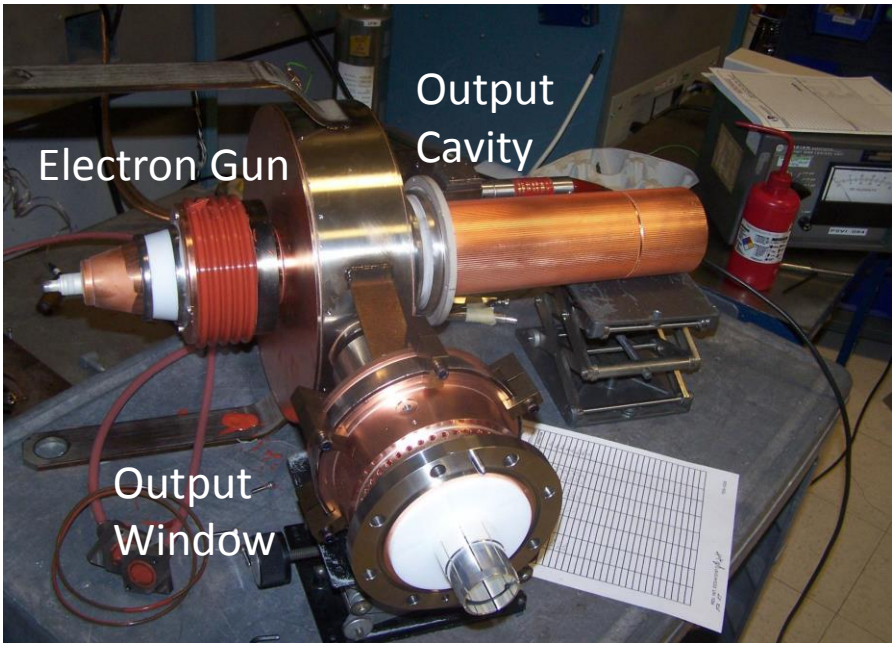




Beam transport simulations

Single beam demonstrator

L3 Electron Devices

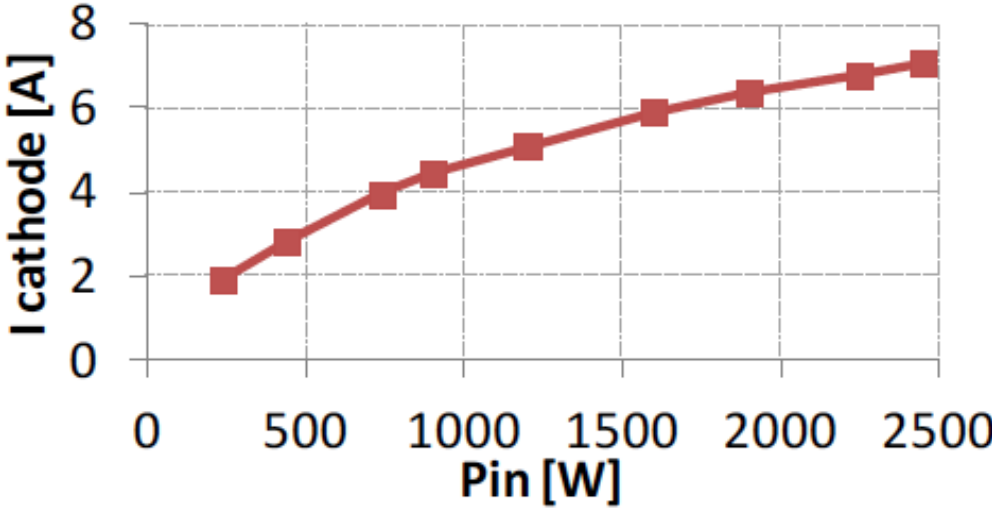


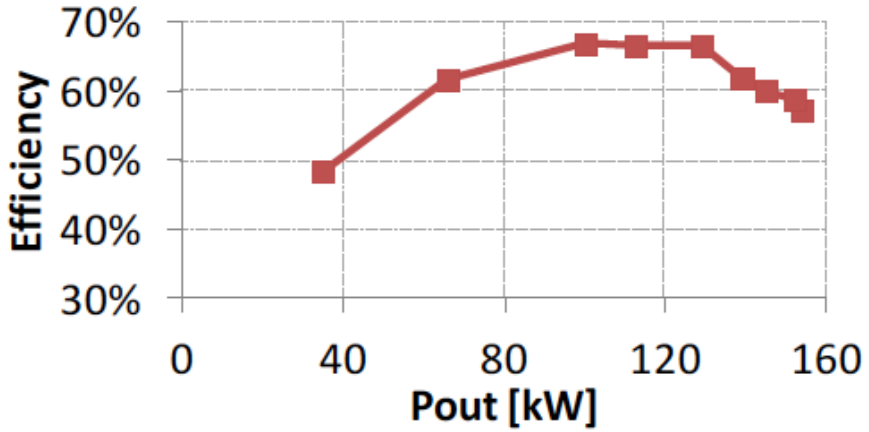
Single Beam IOT

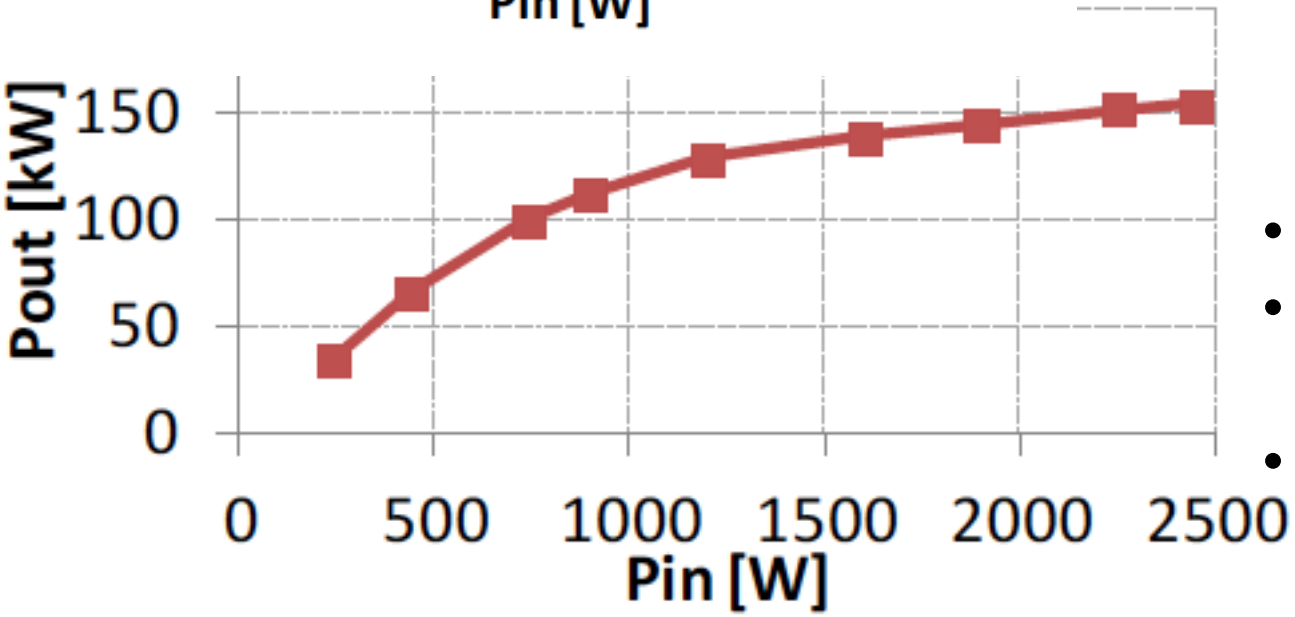
- Single beam output cavity
- Scales output window

Gun Test Vehicle

Single Beam Prototype IOT Test Results



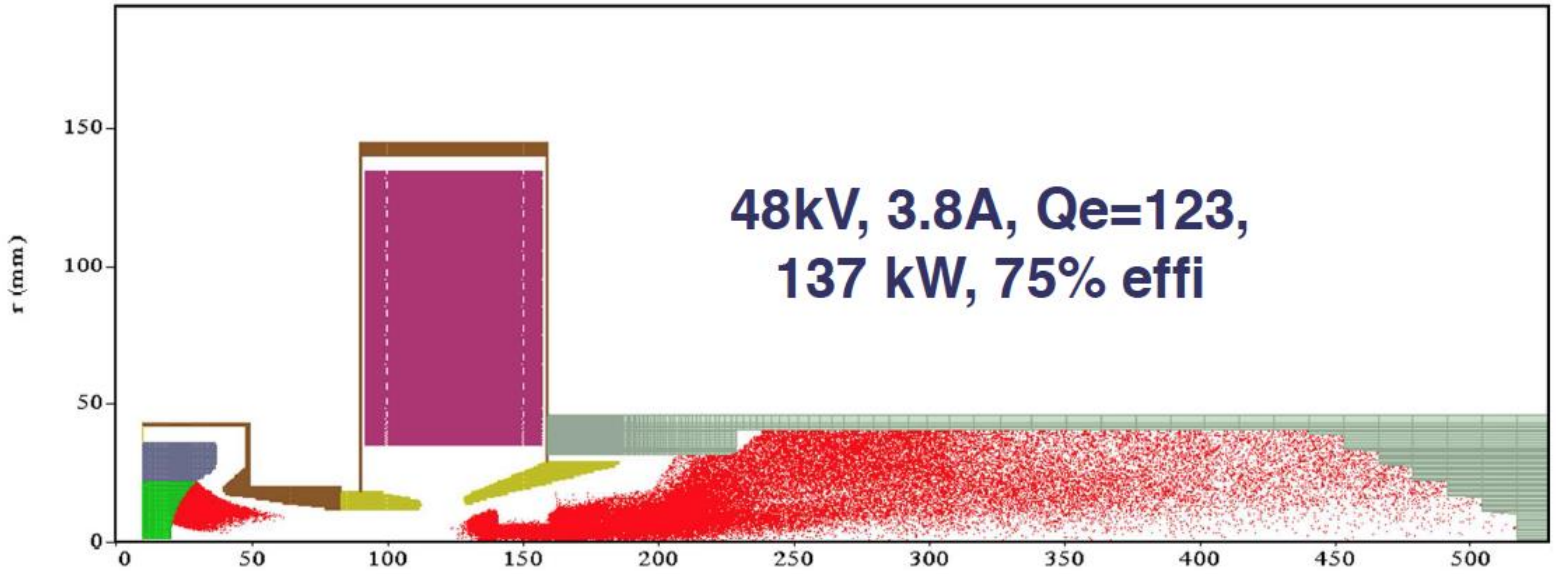




Electron Devices

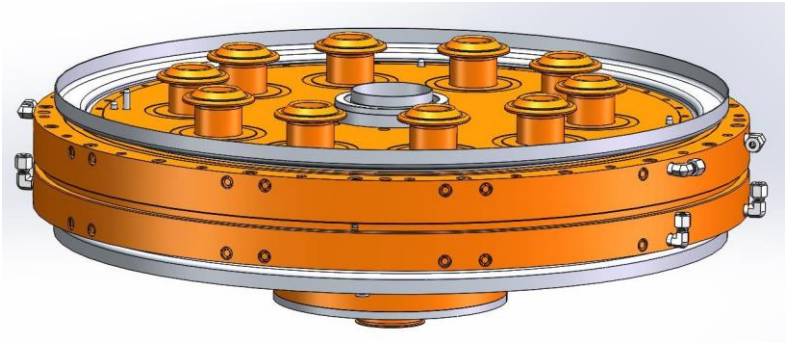
- Tested to 10% duty
- Peak output power 150 kW
- HV limited to 38 kV due to the test stand

Magic-2D Simulation



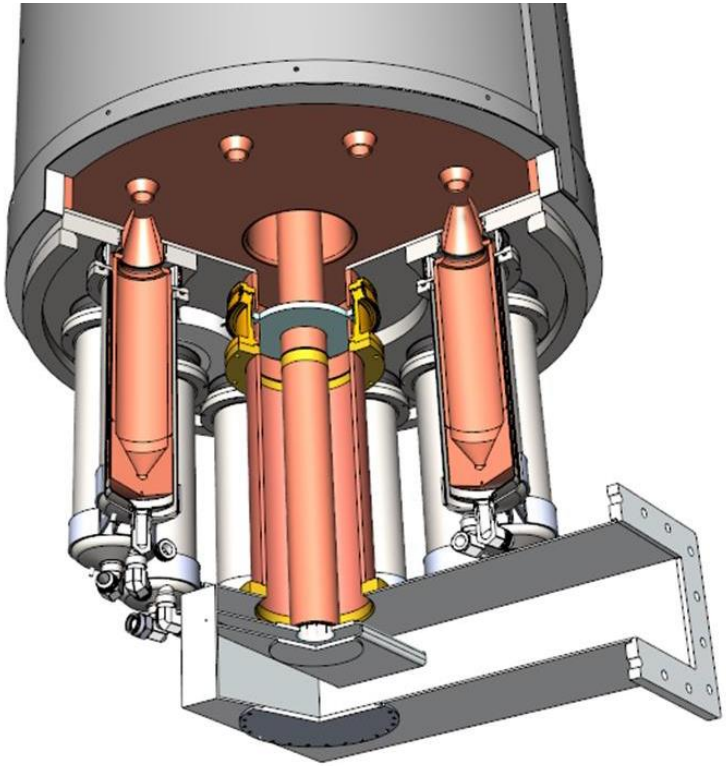
Work still ongoing to optimise optics and beam transport

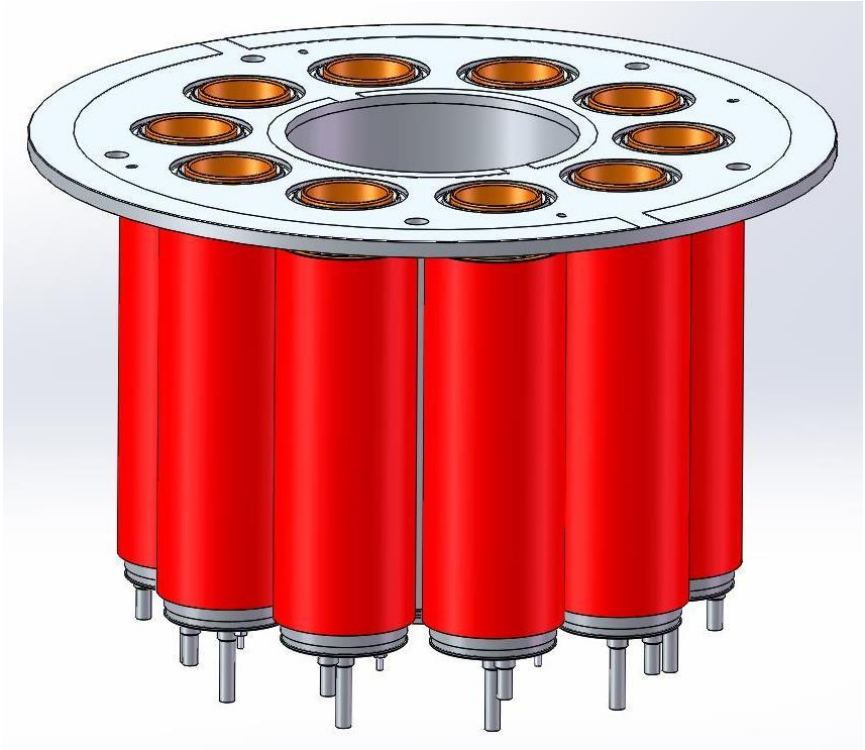
Output Cavity



Collectors

- 10 individual collectors



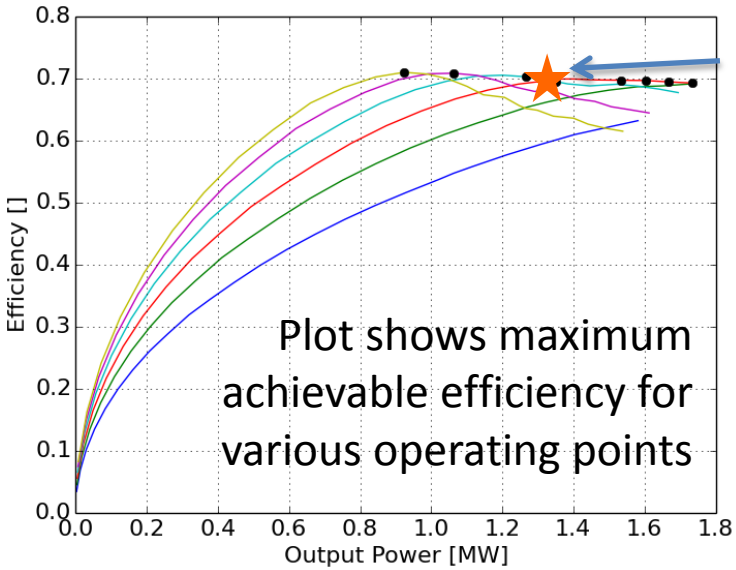


L3 communications

THALES

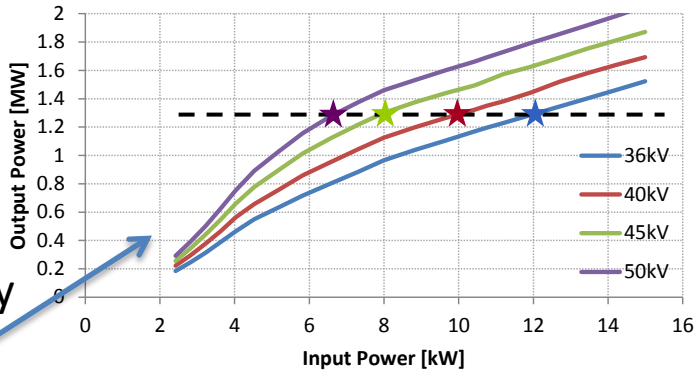
Operational Optimisations
Courtesy of L3 Communications

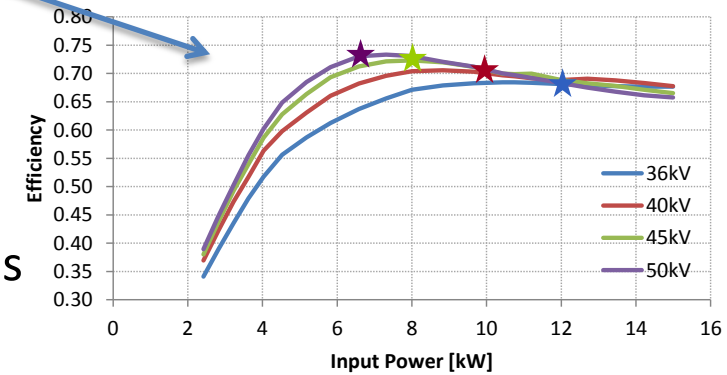
EUROPEAN SPALLATION SOURCE



1.3 MW
70% eff

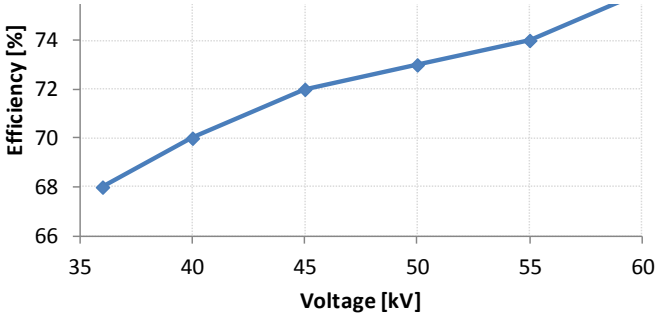
Power and Efficiency
Impact of HV





Increased beam voltage provides for better performance

- Increases gain
- Increases efficiency
- Decreases body current

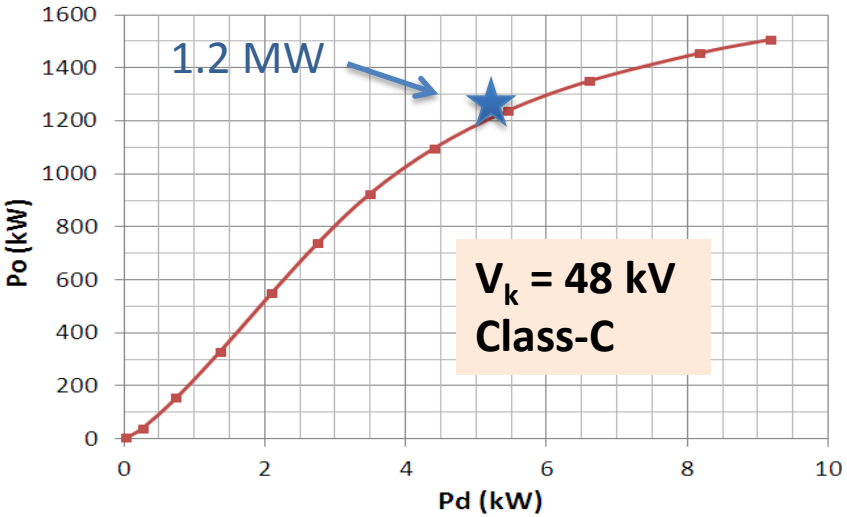


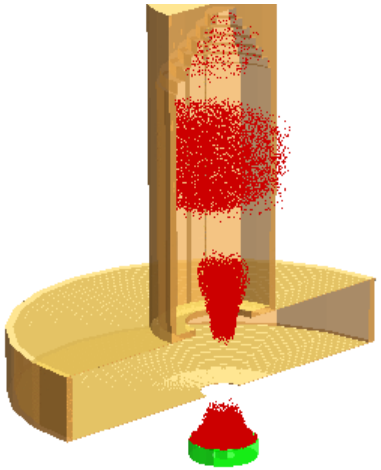
L3 communications

MAGIC Prediction of MB-IOT Performance Courtesy of Thales and CPI

EUROPEAN SPALLATION SOURCE

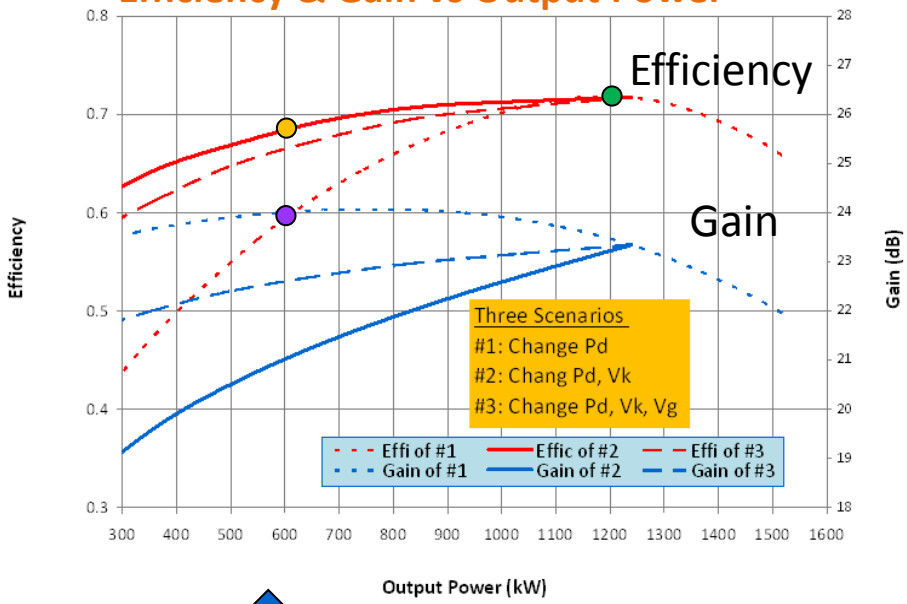
Power Transfer Curve





MAGIC-3D simulation of one beam with MB-IOT off-axis B-field

Efficiency & Gain vs Output Power



- At 1.2 MW, η = 72% with V_k = 48 kV
- At 600 kW
  - η = 59% with V_k = 48 kV
  - η = 68% with V_k = 34 kV

CPI THALES

Integration Test Stand

Integration test stand being prepared

- First setup will be with CERN modulator and klystron
- Spring/summer 2016 test with ESS modulator and klystron prototypes

Old LEP Klystron, PPT modulator, distribution etc

Thanks to RF Group for help with the presentation

To Chiara Marrelli, Rafael Montano and Rutambhara Yogi for slides

L3 and Thales/CPI for permission to publish some of the results and design details