High Power RF Sources for the ESS RF Systems

Morten Jensen

Co Authors:

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www.europeanspallationsource.se

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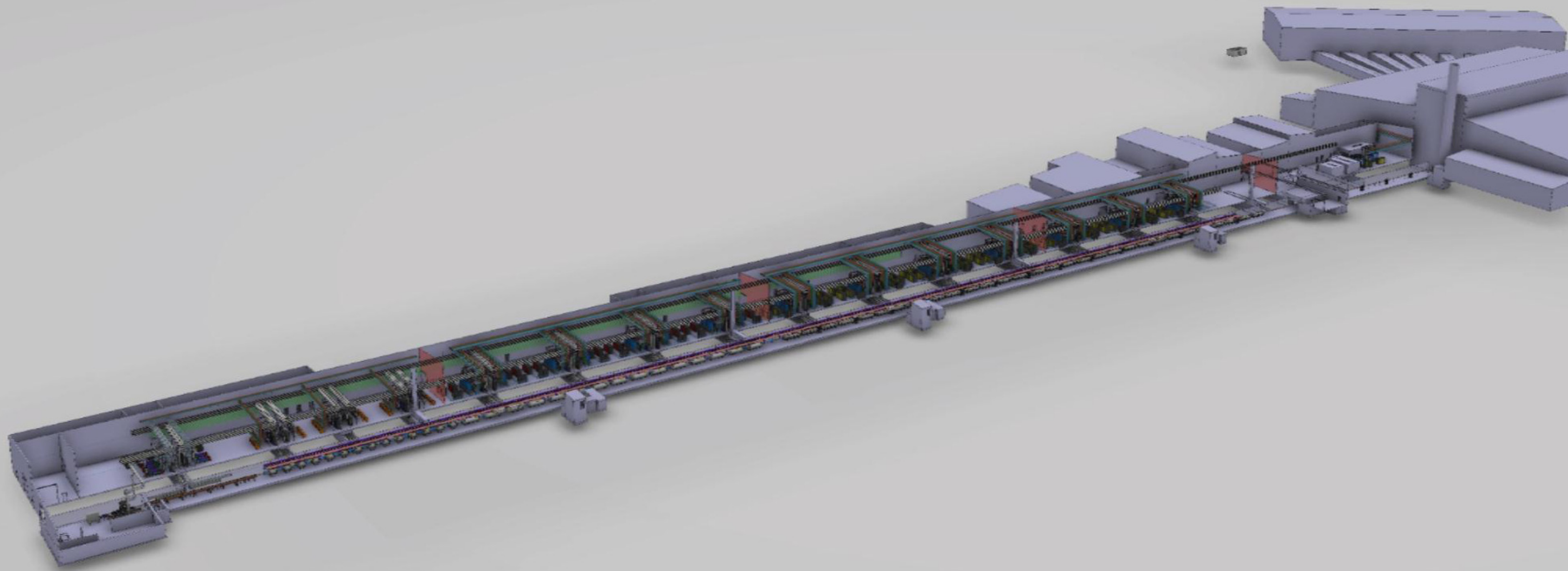
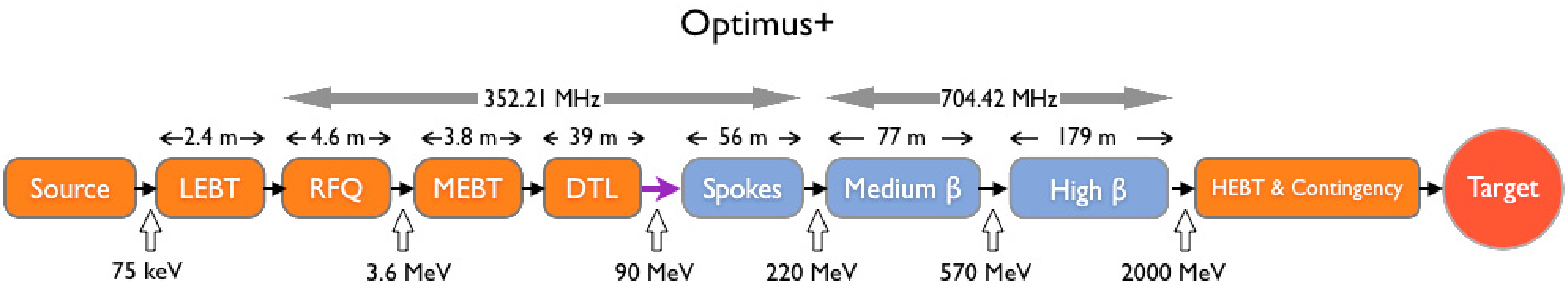
Agenda

- Introduction to ESS
- Power profile and Technology Choices
- IOTs



Linac Design Choices

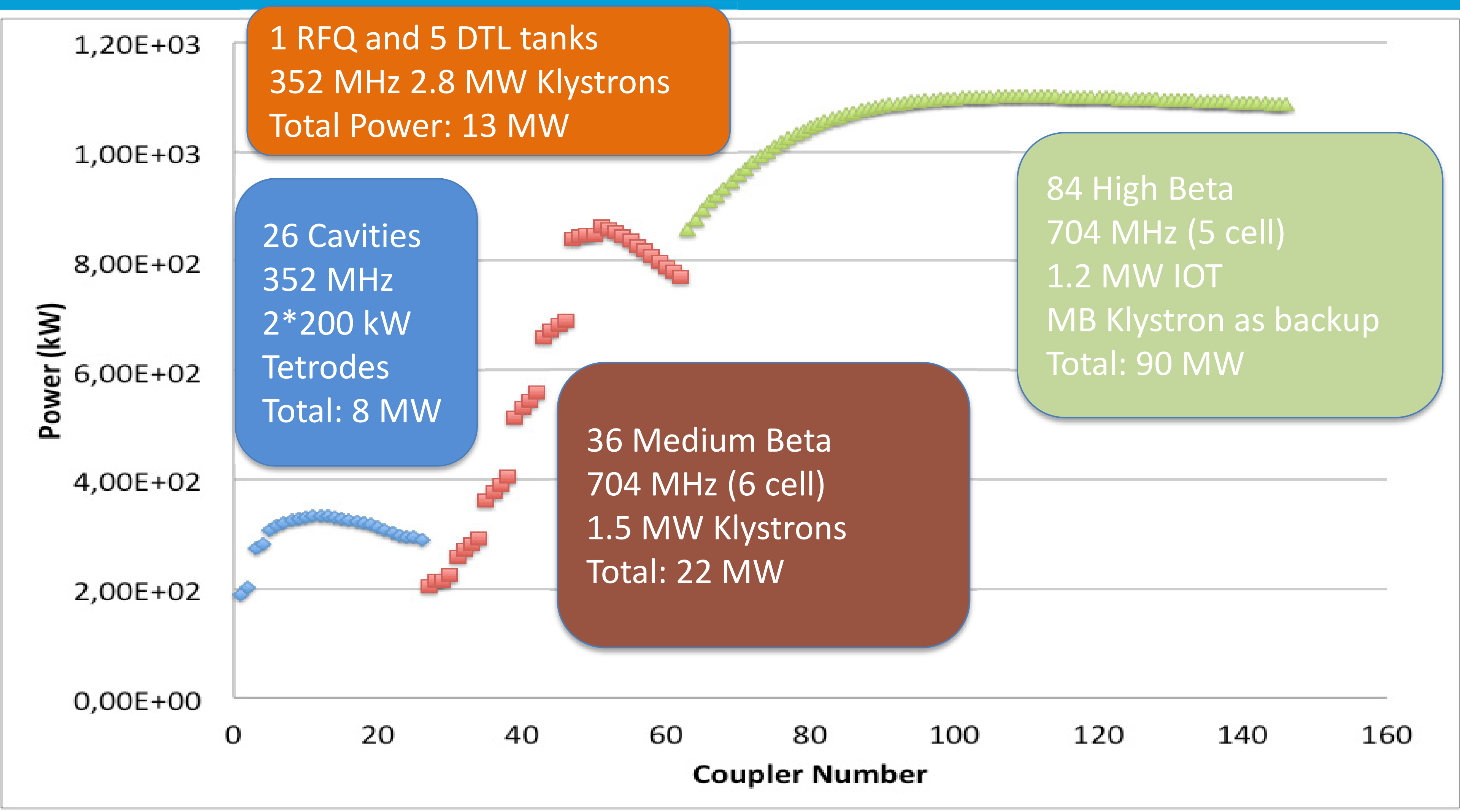
- User facilities demand high availability (>95%)
- The linac will be mostly (>97%) superconducting
- Front end frequency is **352 MHz** (CERN Standard)
- High energy section is at **704 MHz**
- ESS will limit the peak beam current below **62.5 mA** (was 50 mA)
- Linac Energy of 2 GeV - **125 MW** peak power.



The ESS Superconducting Power Profile

> 150 cavities/couplers

EUROPEAN SPALLATION SOURCE



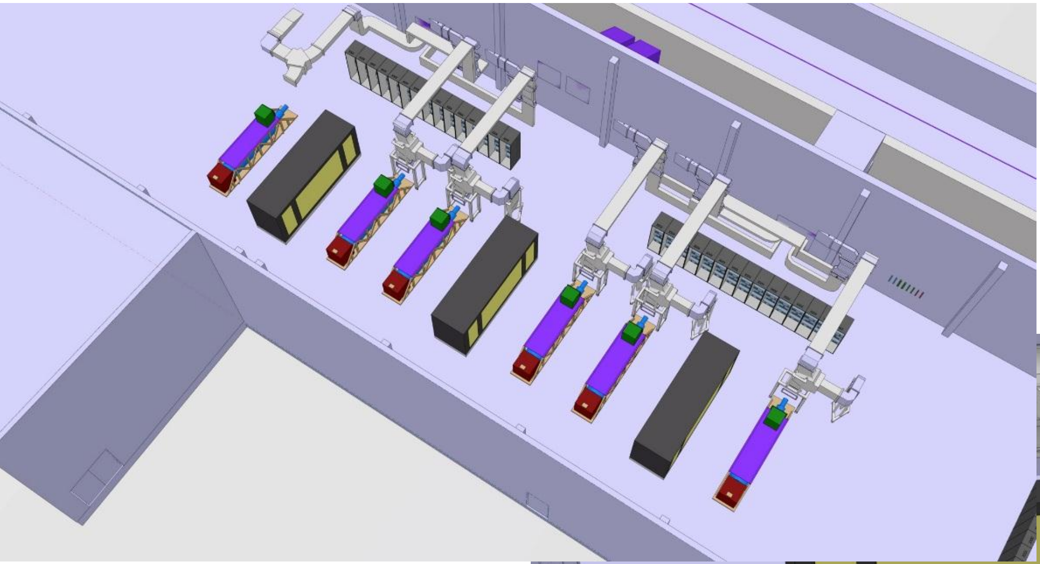
Total High Power RF: 133 MW peak (4% duty) plus overhead

RF distribution for the RFQ and 5 DTLs Layout being finalised

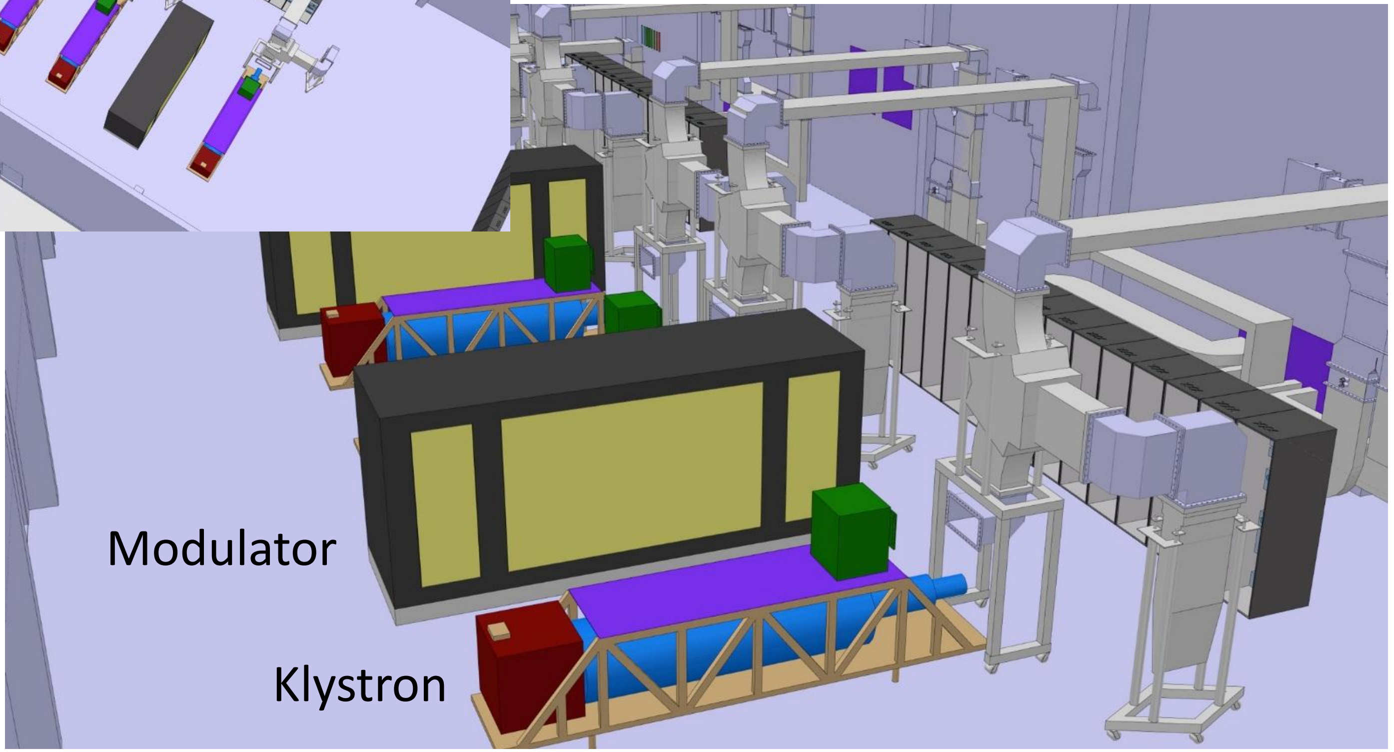
One 2.8 MW for RFQ
Five 2.8 MW klystrons for DLT

Power split to two couplers per DTL tank

CPI – VKP-8352B
Thales – TH2179

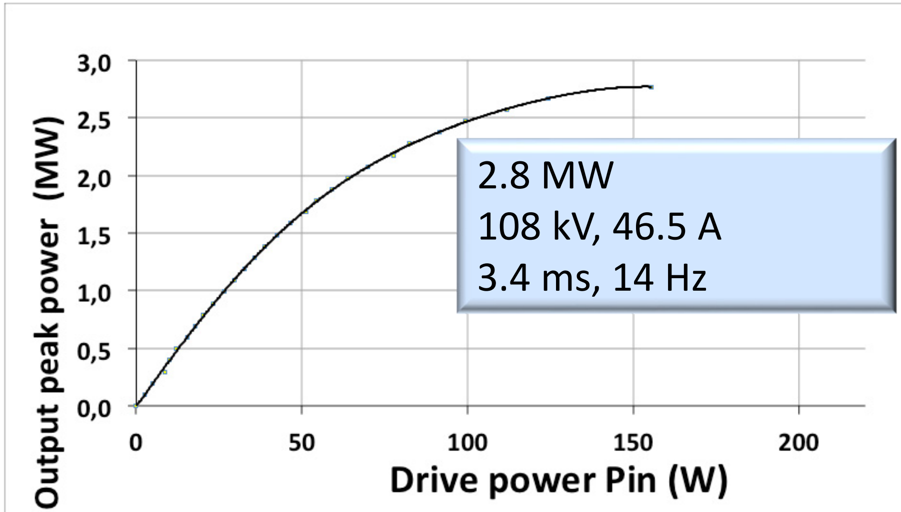


2 Klystrons per modulator

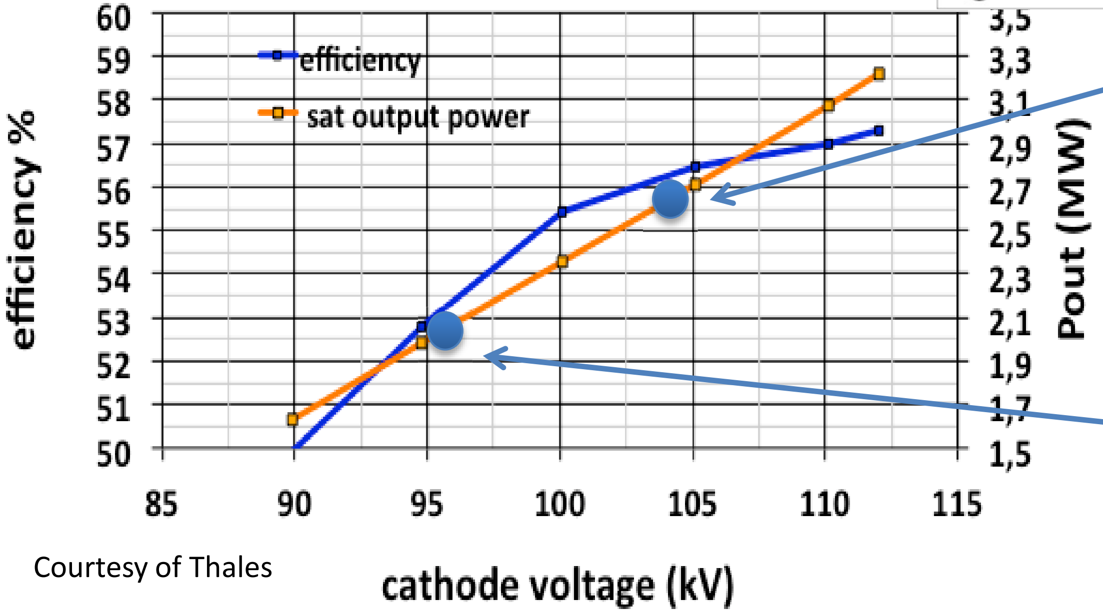


Possible RFQ and DTL Power Source

EUROPEAN SPALLATION SOURCE



Investigating option to operate at lower voltage for lower power operation



Courtesy of Thales

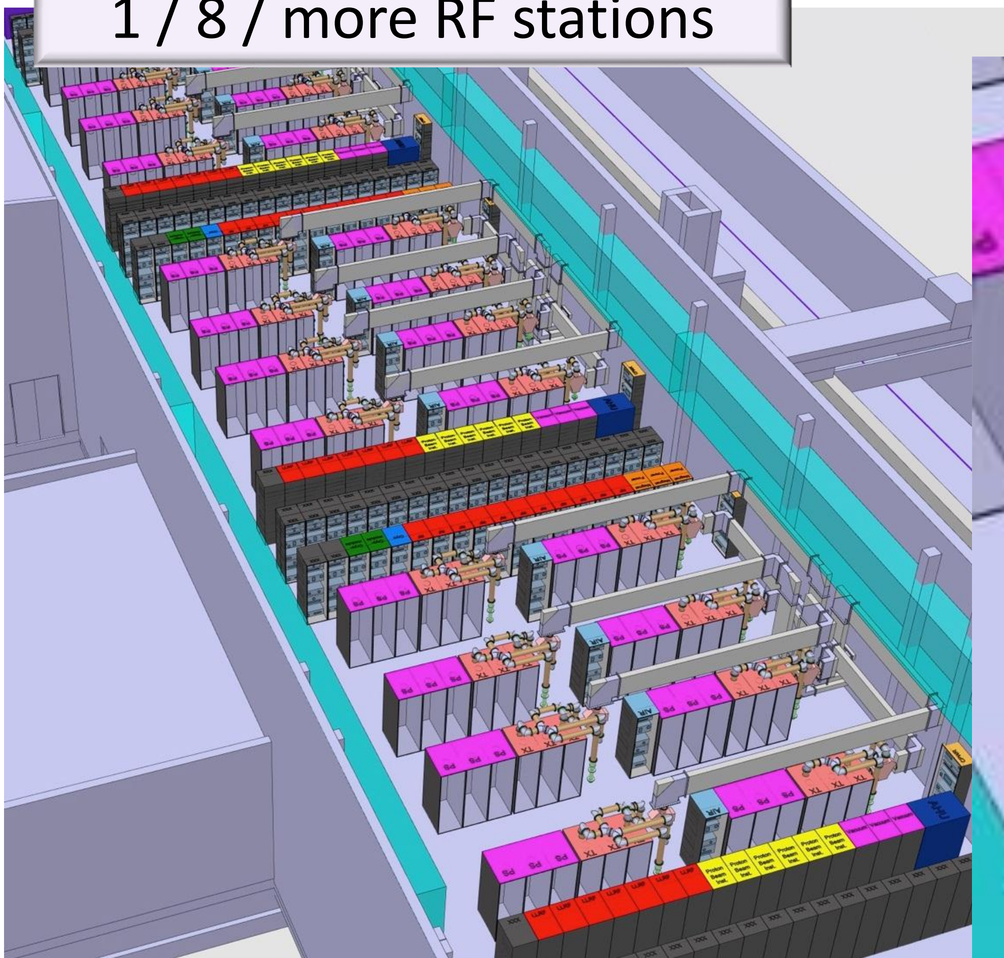
DTL:
Saturation efficiency = 55%
Beam efficiency = 46%
Full voltage efficiency = 41%

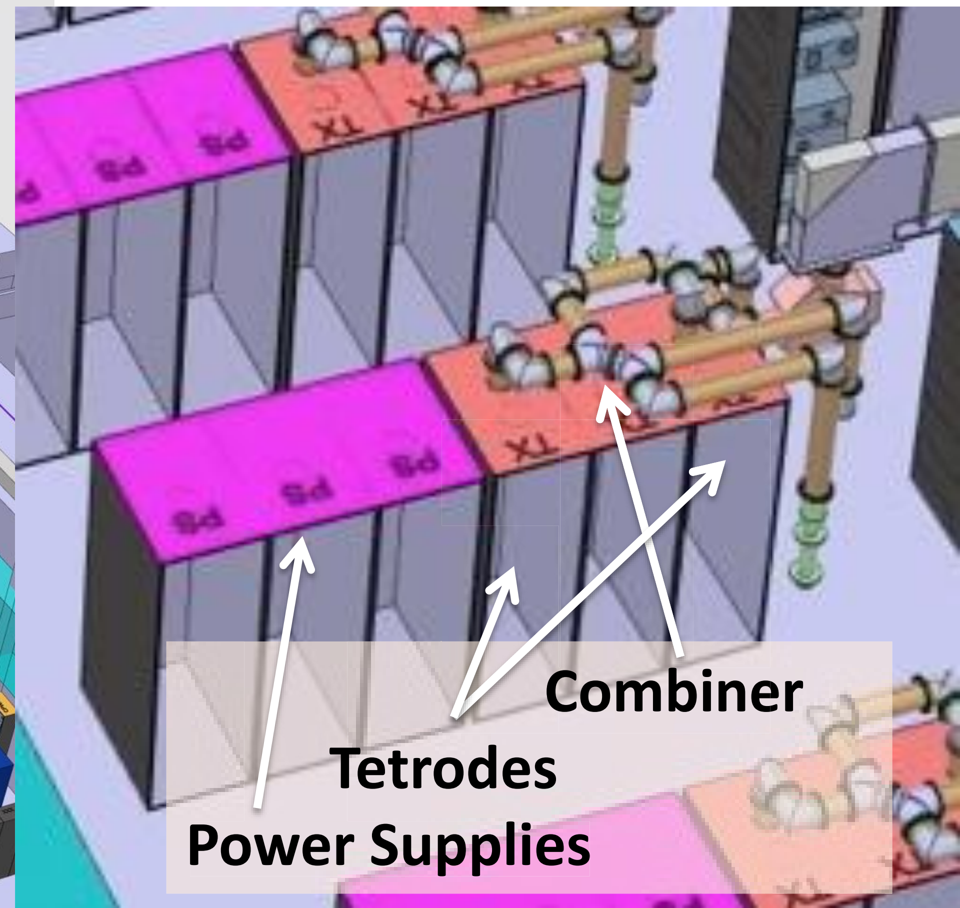
RFQ:
Saturation efficiency = 52%
Beam efficiency = 43%
Full voltage efficiency = 31%

Spoke linac (352 MHz) RF System Layout

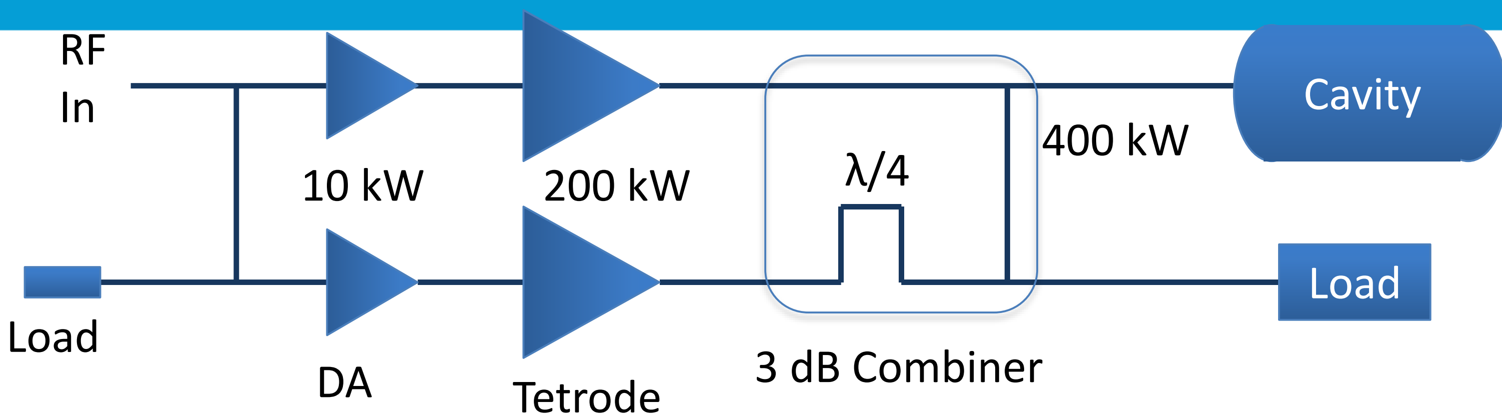
Conceptual Only

26 Double Spoke cavities
Considering: 1 PSU per
1 / 8 / more RF stations





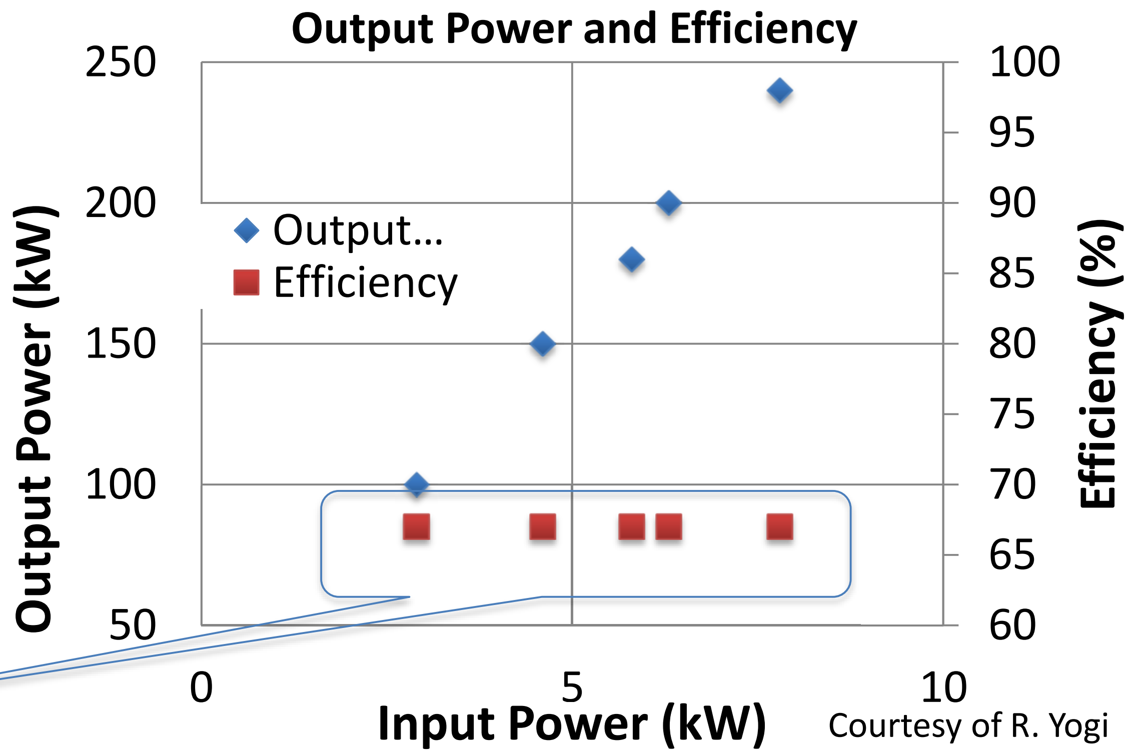
Spoke linac RF System



TH595 Tetrode

Individual or common (tetrode) driver
Circulator under consideration

High efficiency at point of operation
Margin for overhead

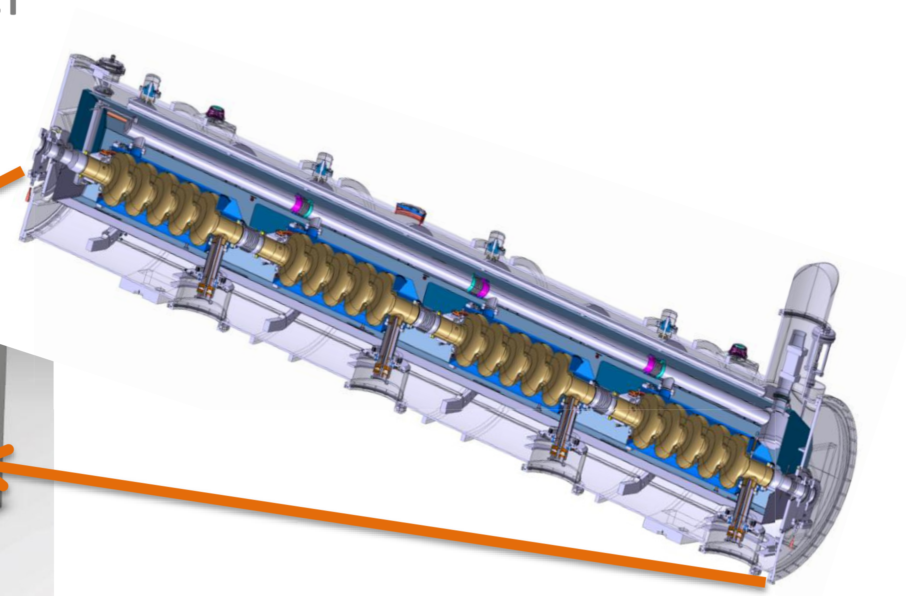


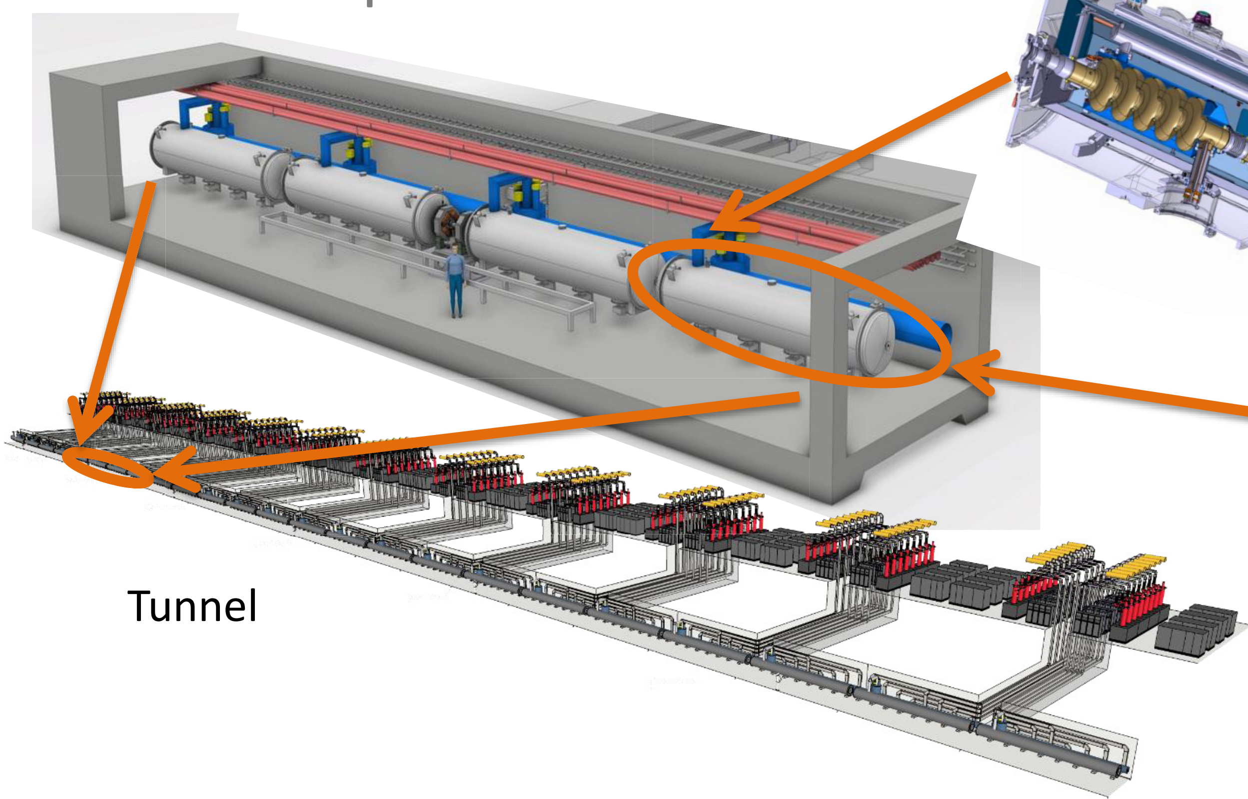
Courtesy of R. Yogi

Anode efficiency > 65%
at all power levels

Elliptical (704 MHz) RF System Layout

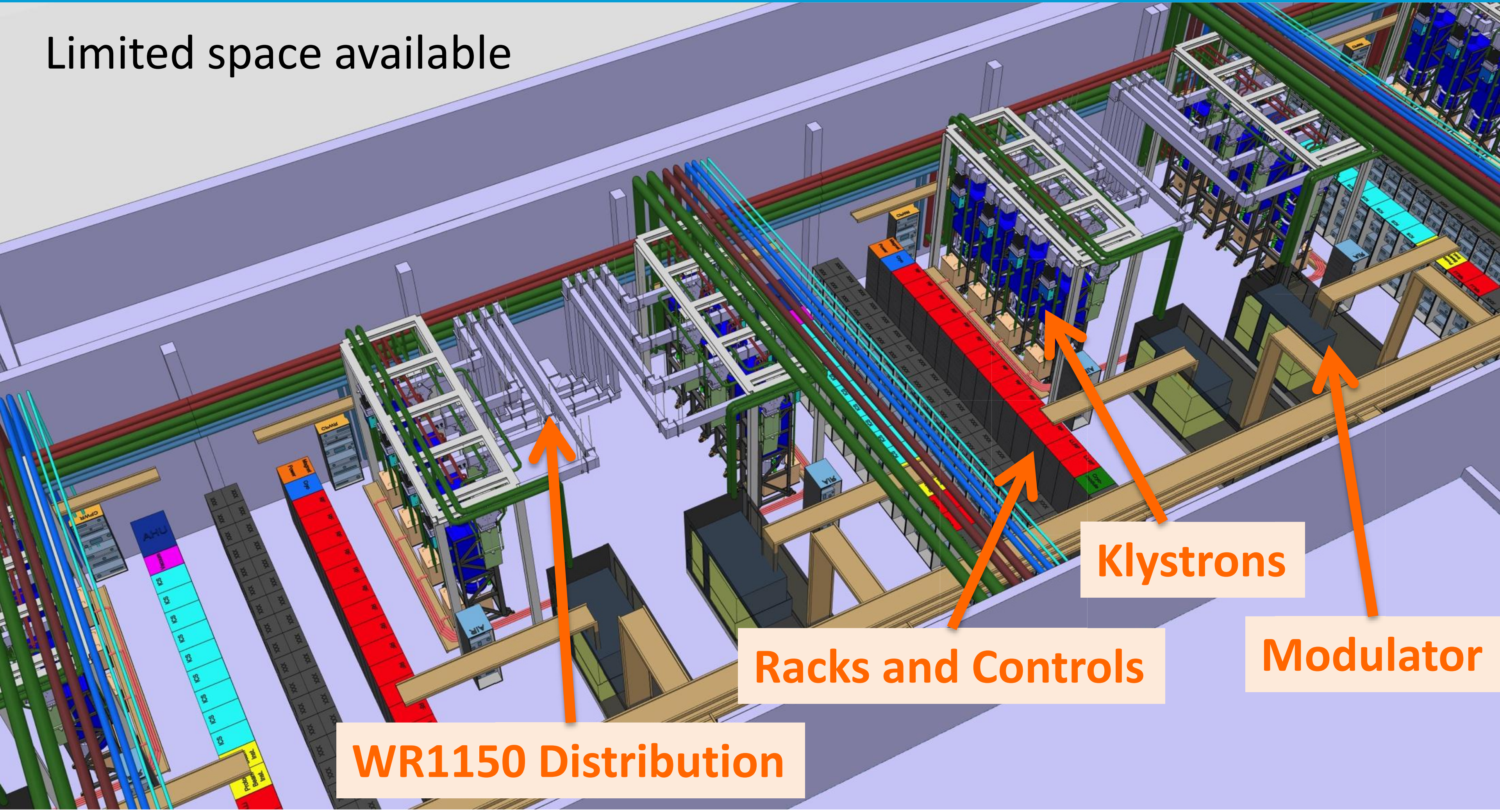
- One cavity per klystron
- 4 klystrons per modulator
- 16 klystrons per tunnel penetration





Elliptical (704 MHz) RF System Layout

Limited space available



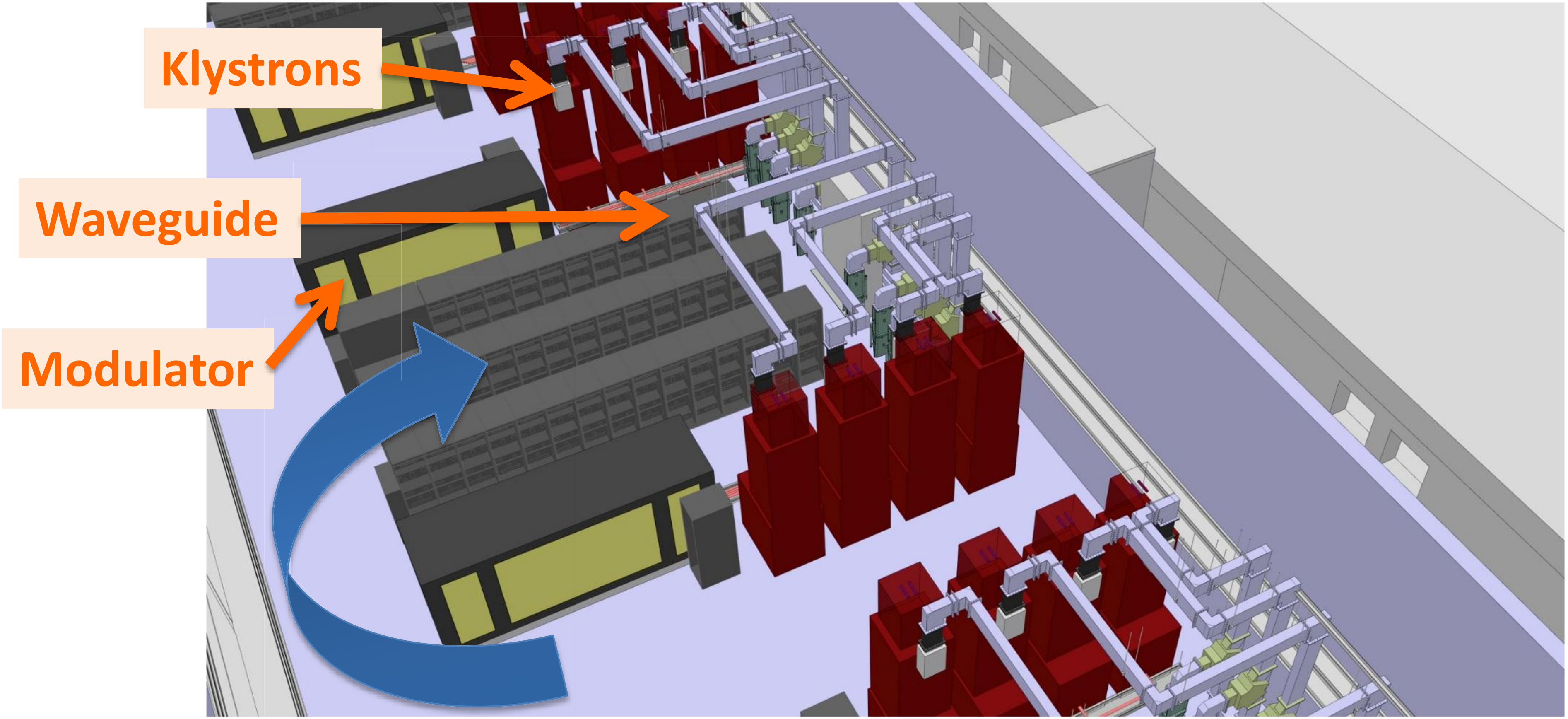
4.5 Cells of 8 klystrons for Medium Beta

10,5 Cells of 8 klystrons (IOTs) for High Beta

Elliptical (704 MHz) RF System Layout

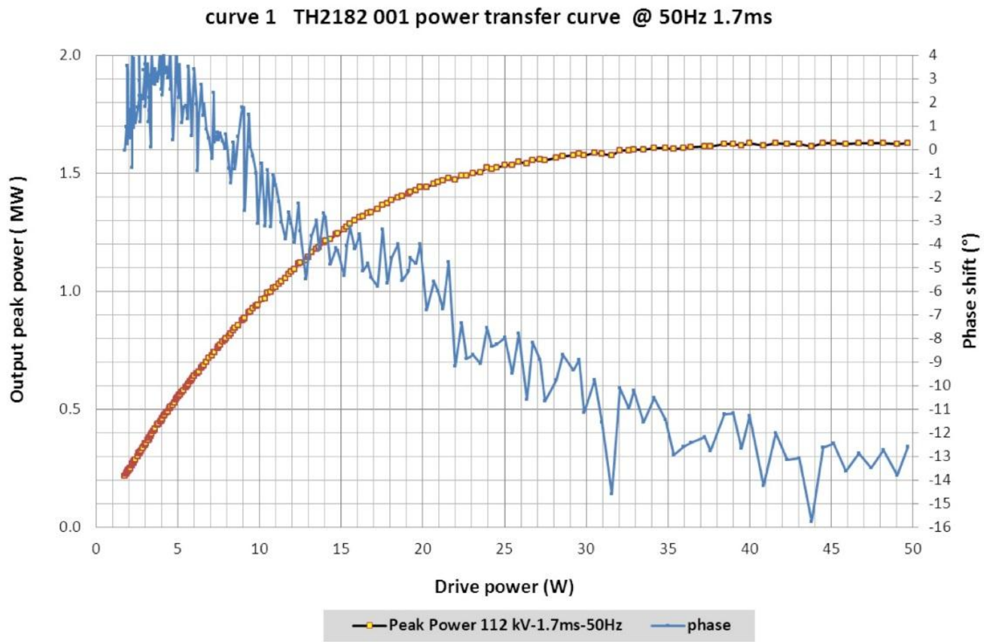
(but last week it may have changed)

EUROPEAN SPALLATION SOURCE



Racks moved to allow the cables to follow the route of the waveguide

704 MHz Klystron (Thales) factory tests



Courtesy of Thales
and CERN

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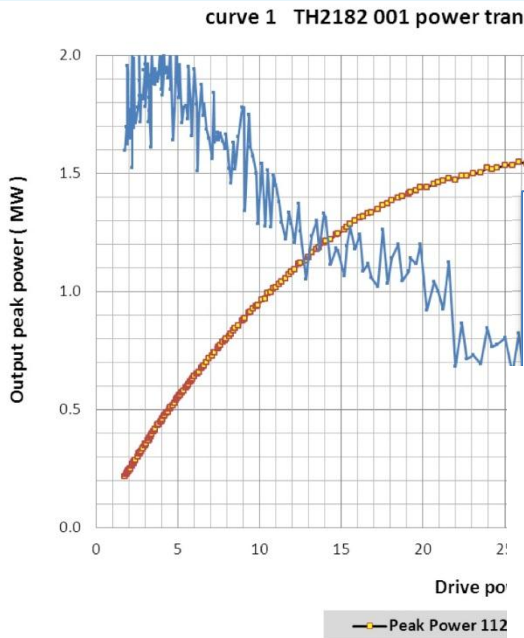
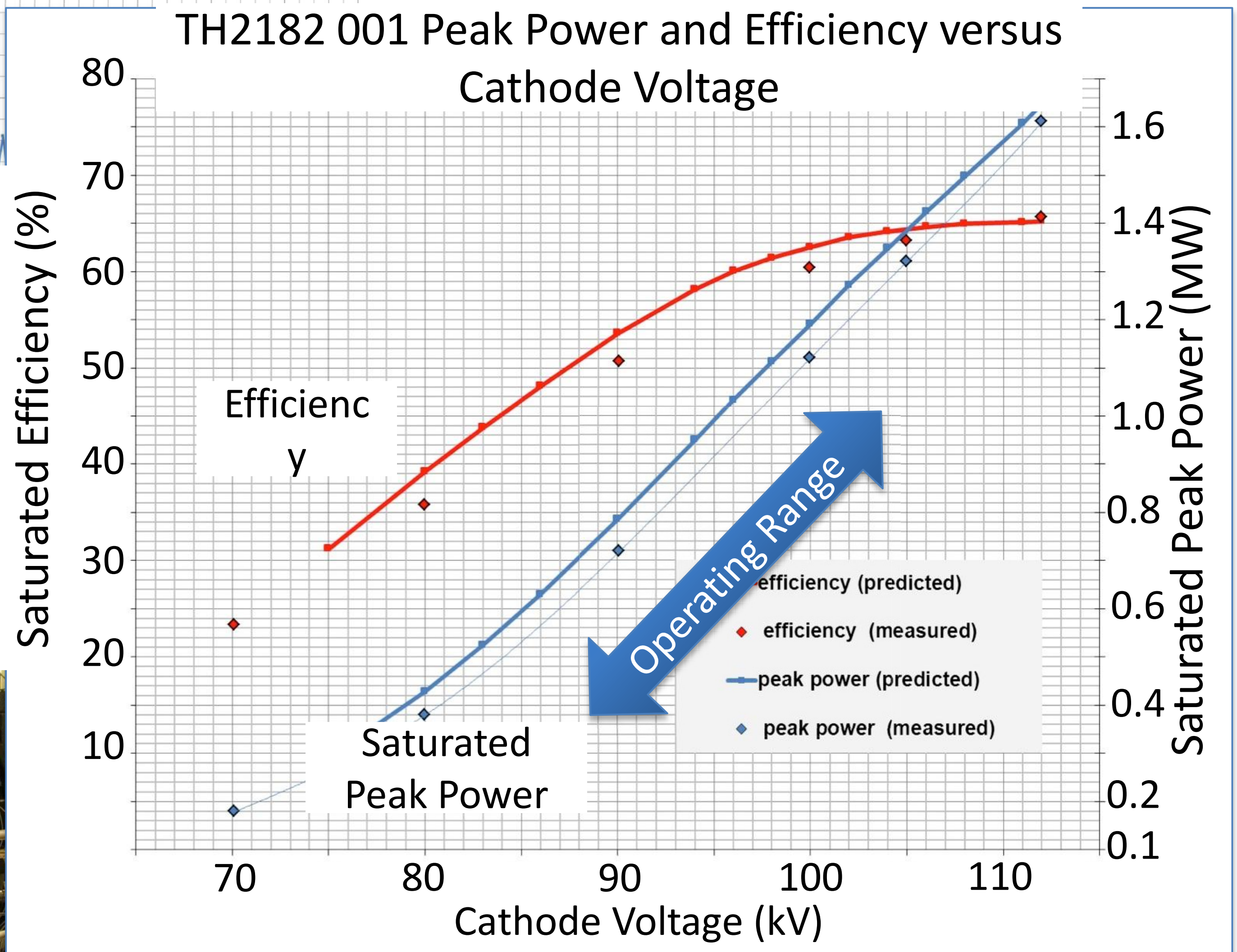
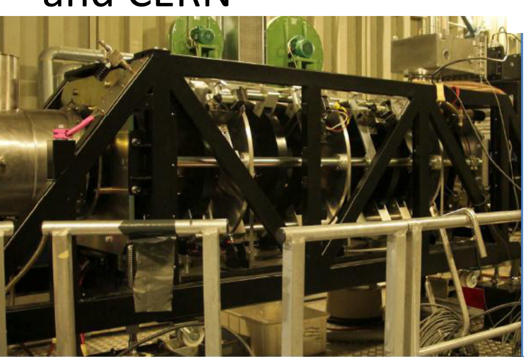




Courtesy of Thales and CERN



An RF Source for a Proton Linac

EUROPEAN SPALLATION SOURCE

- NC cavities with electrons
  - Operation at full power
  - ‘Easy’ to manufacture
  - Long cavity strings, no Lorentz detuning
  - Flat power profile – large source feeding many cavities

Very high power klystron is a good match

- Compared to copper cavities, superconducting cavities offer:
  - over three times the gradient
  - over 10 times the aperture
  - with virtually no power dissipated in the cavities

- SC cavities are difficult to manufacture
- Cell structure designed for one beam velocity
- Power profile shaped by transit time effects
- Strong individual Lorentz detuning
  - Short Cavity strings – lower power
  - One amplifier per cavity

SRF supported by R&D and investment

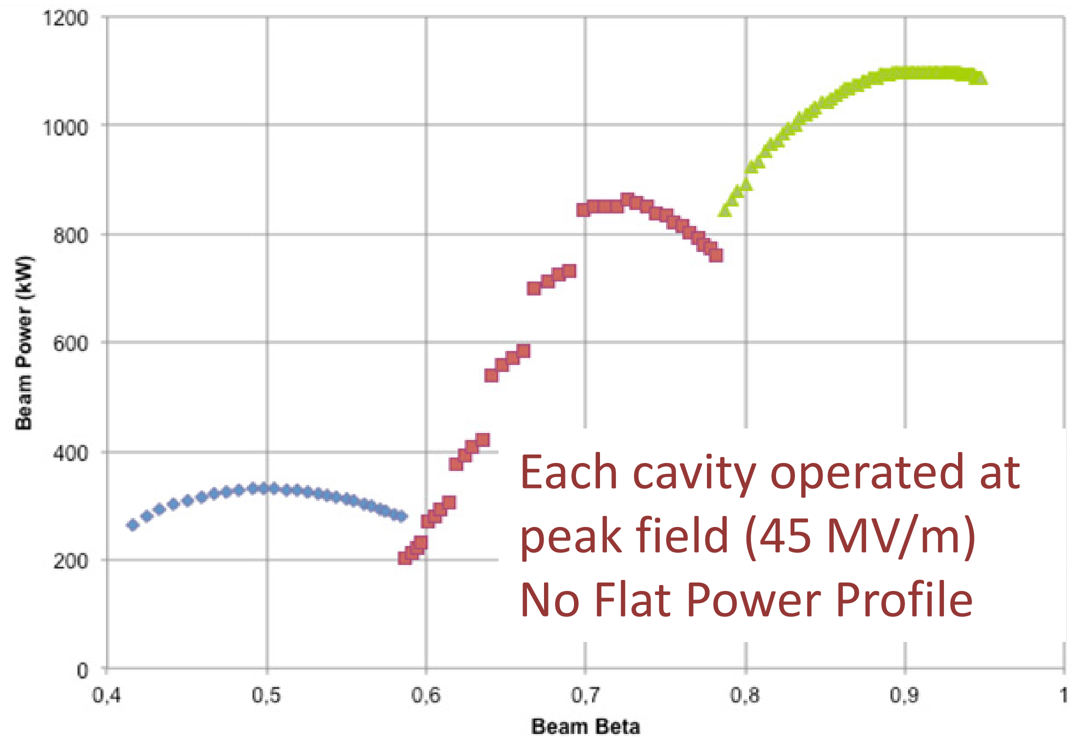
An RF Source for a Proton Linac

Investment in SRF has not been matched with investment in high efficiency RF sources

In a klystron operation below saturation is inefficient
and reduces ‘actual’ efficiency

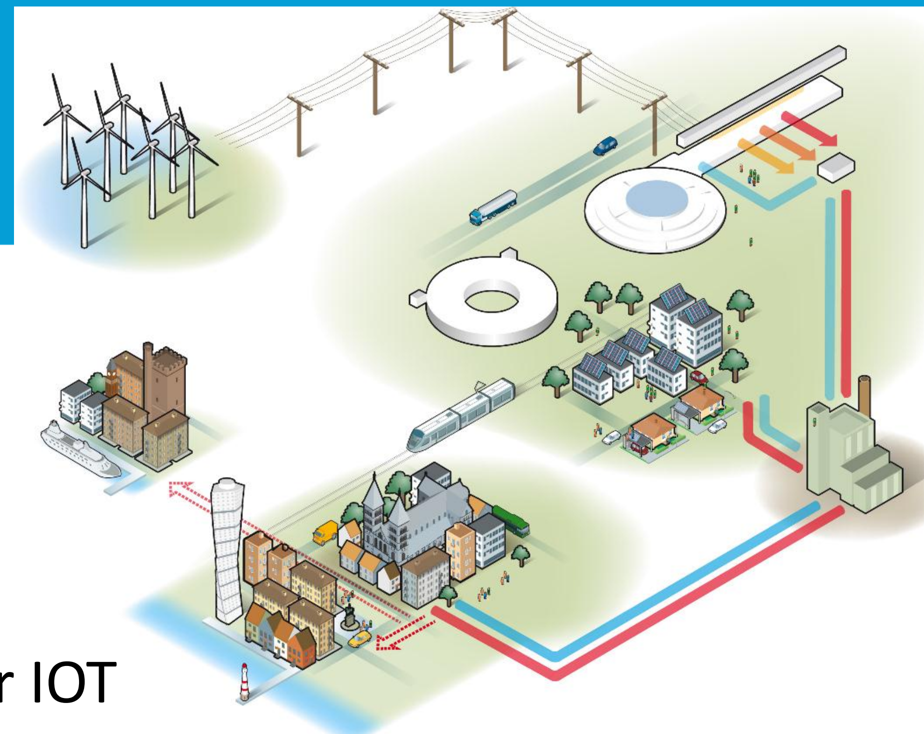
Power-to-beam efficiency
≤ 43 %

Power Profile



Where next?

The ESS Requirement



Carbon Neutral

Innovative

Green

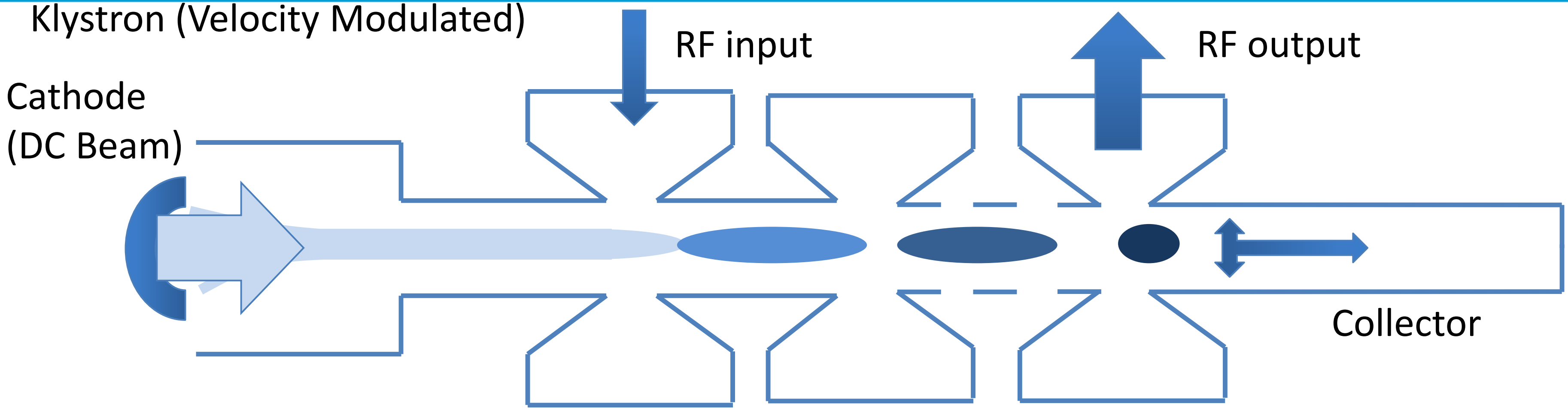
Opportunity to develop Super Power IOT

Accelerating Structure	Freq. (MHz)	Quantity	Max Power (kW)
RFQ, DTL	352	5	2200**
Spoke	352	30	330**
Elliptical Medium Beta	704	34	860**
Elliptical High Beta	704	86	1100**

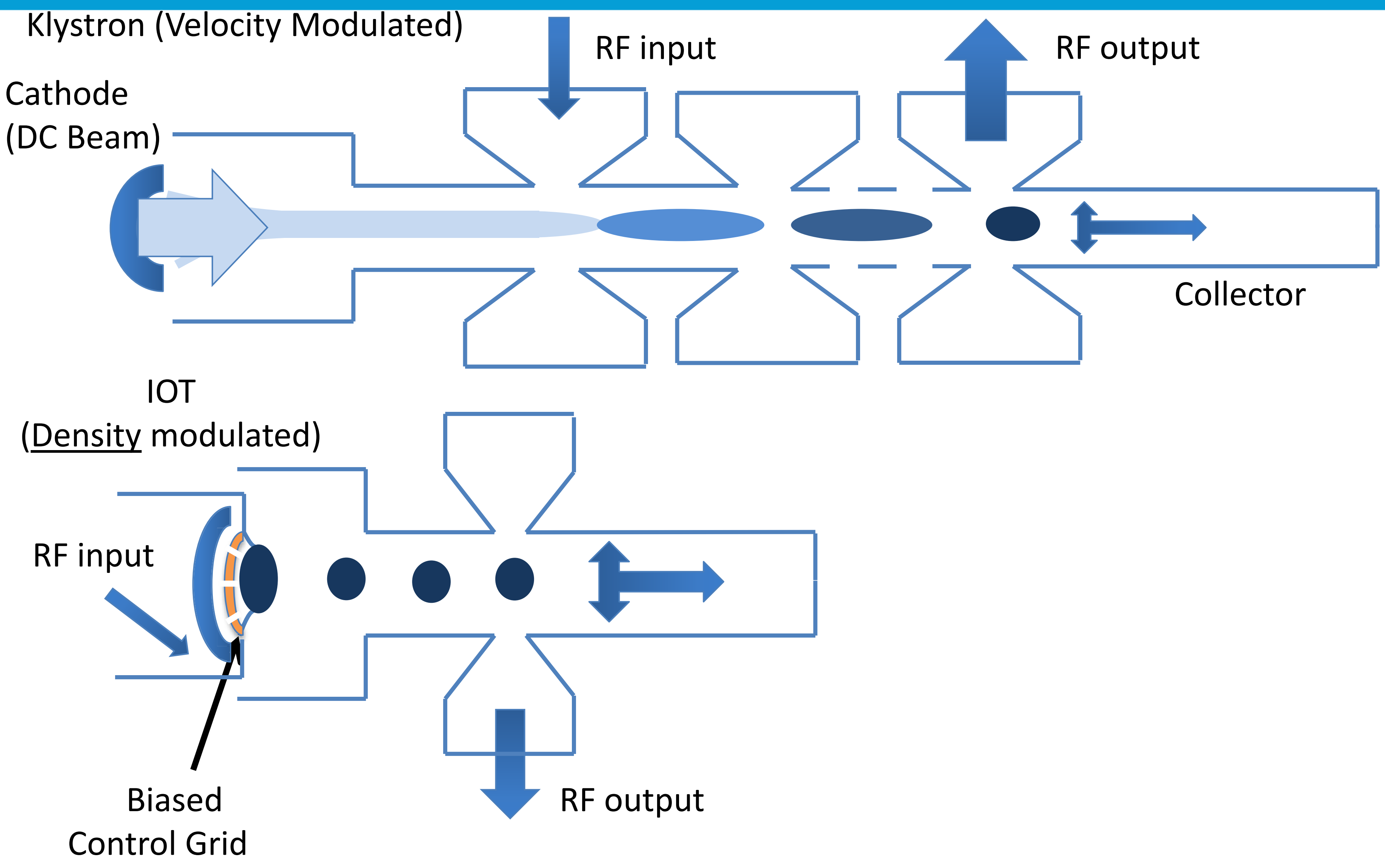
** Plus overhead for control

Klystron and IOT Principles

Klystron (Velocity Modulated)



Klystron and IOT Principles



Reduced velocity spread

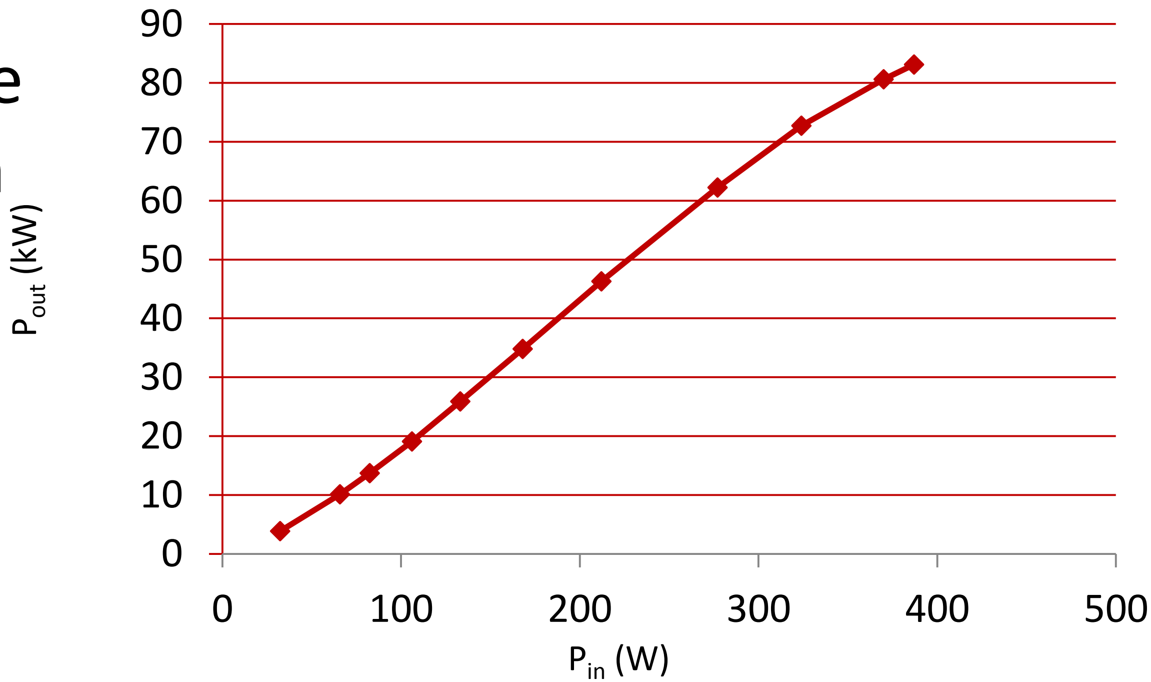
Higher efficiency

No pulsed high voltage

No classical saturation

Typical Example of 80 kW IOT

Tuned for 80 kW @ 36 kV



Courtesy of e2v

Tube History:

Invented in 1938 by Andrew V. Haeff as a source for radar.

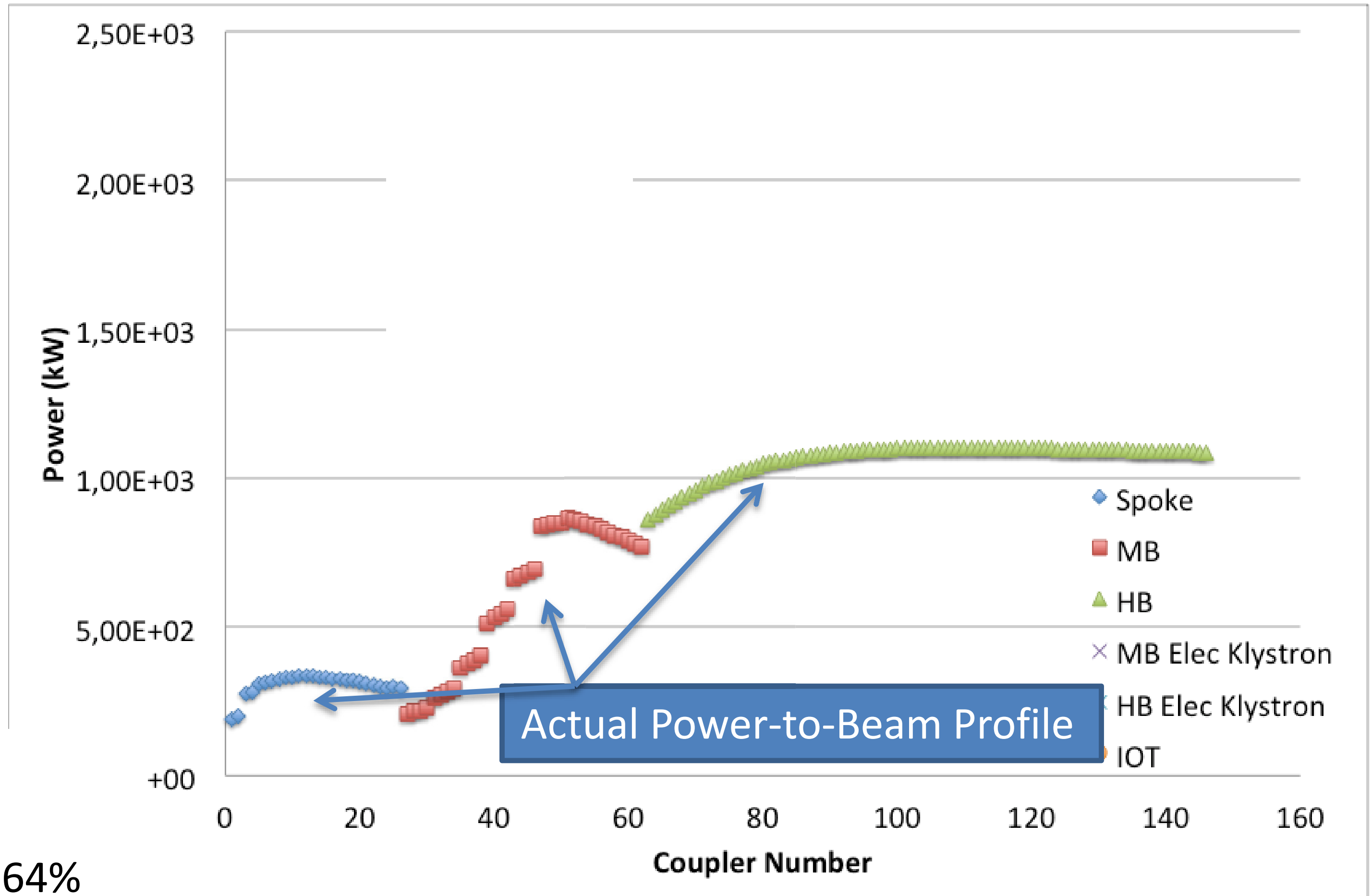
Used first in 1939 to transmit television images from the Empire State Building to the New York World Fair.

Difficult to manufacture.

An RF Source for a Proton Linac

EUROPEAN SPALLATION SOURCE

Each marker is an RF Source



Assume 25% overhead

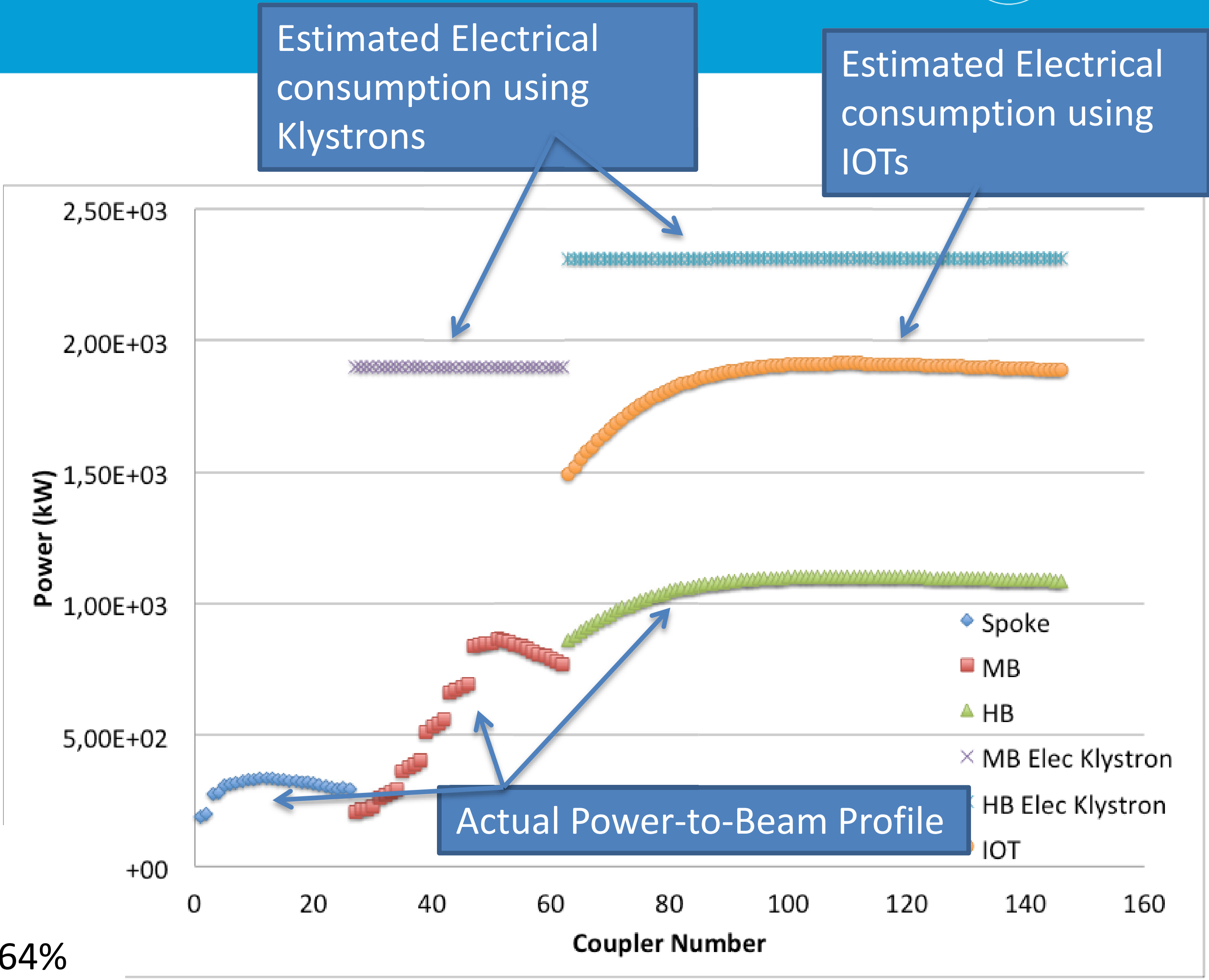
Modulator η= 93%

Klystron saturation η = 64%

IOT η = 65%

An RF Source for a Proton Linac

Each marker is an RF Source



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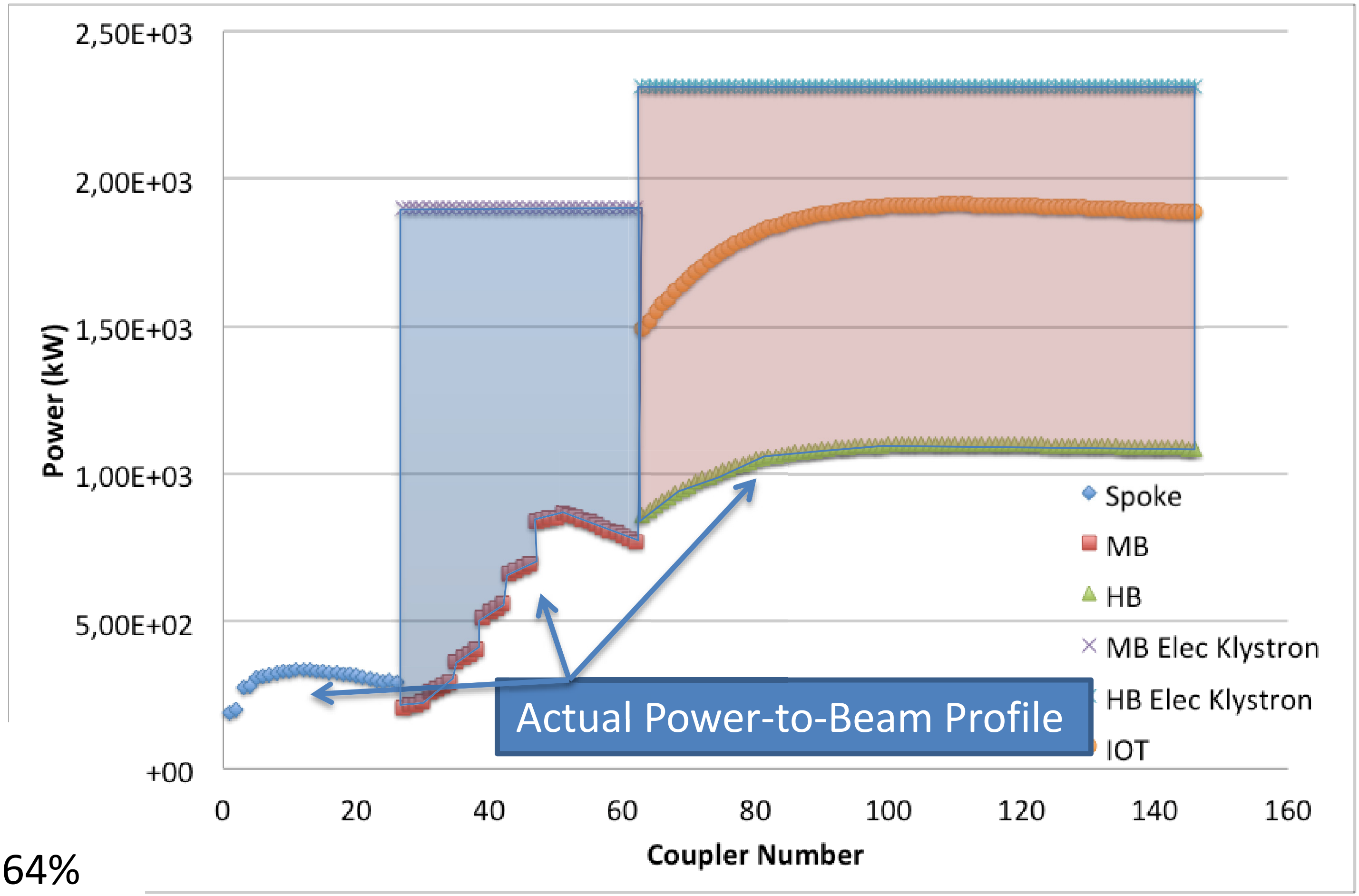

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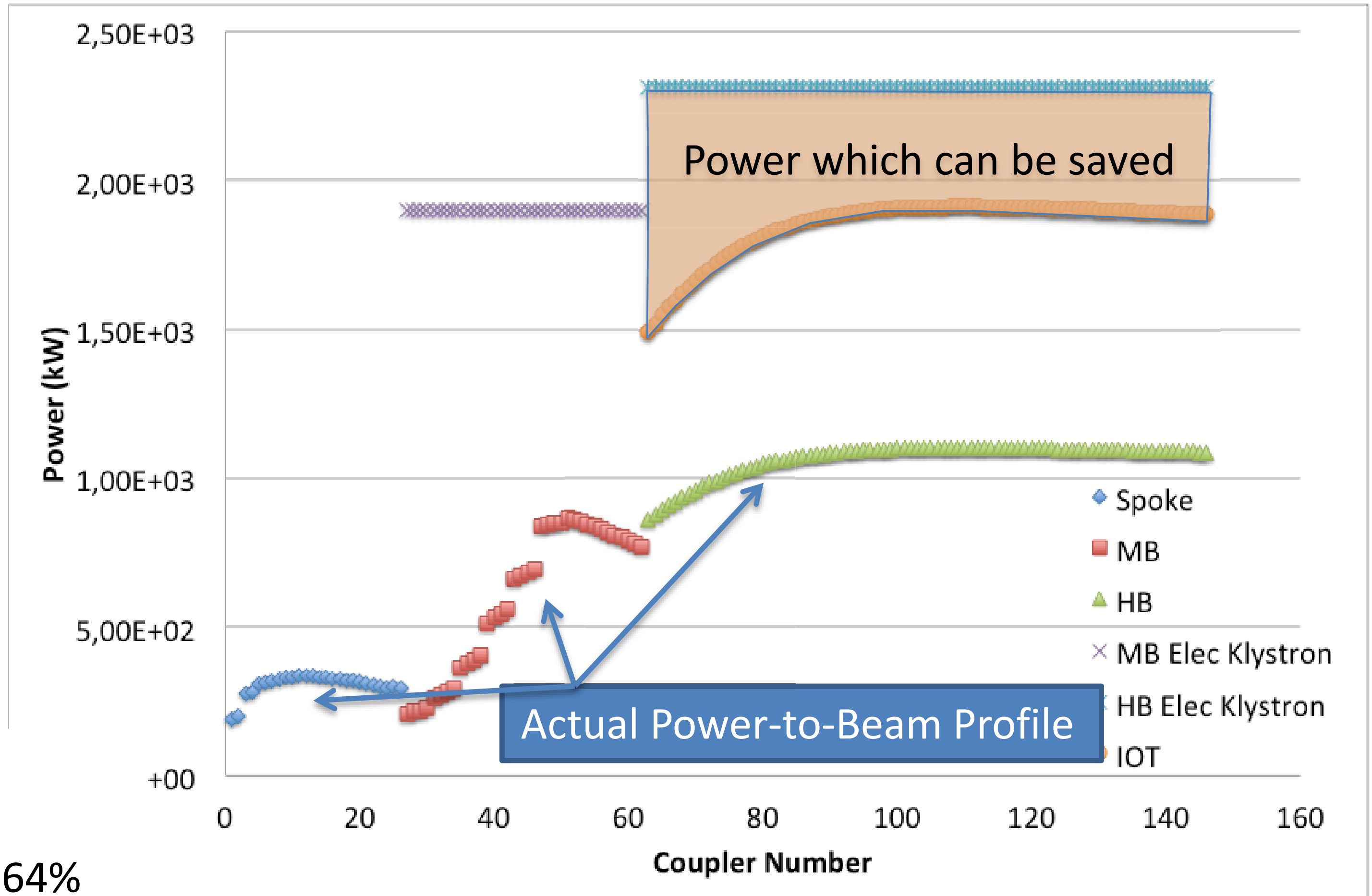

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An IOT for ESS

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 is being carried out in collaboration with CERN

- ESS to procure prototypes
- CERN to make space and utilities available for testing

Target: Approval for ESS series production in 2017/18

A 3rd Generation Light Source Storage Ring

Three 500 MHz 300 kW amplifier for SR

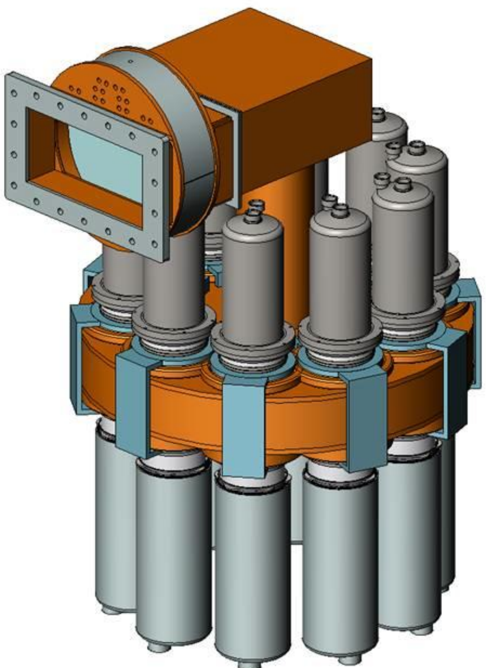
- 4 x 80 kW IOT combined

One 80 kW for the Booster

Other examples of IOTs exist throughout Europe
… but not at MW power levels

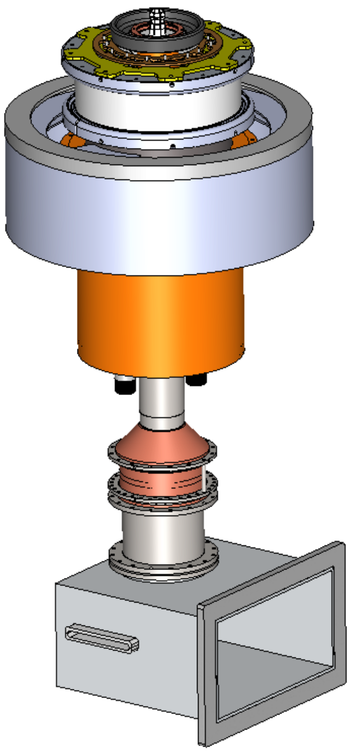
1.2 MW Multi-Beam IOT

EUROPEAN SPALLATION SOURCE



Electron Devices

- ESS launched tender for IOT prototypes
- Tender replies received and contracts about to be signed for two IOTs
- Delivery in 24 months
- Site acceptance at CERN followed by long term soak test
- ESS > 3 MW saved from from high beta linac = 20 GWh per year



Pre-tender
CPI Cartoon

Summary of Key Parameters for the ESS High Power Devices

EUROPEAN SPALLATION SOURCE

	Klystron 352 MHz	Tetrode* 352 MHz	Klystron 704 MHz	IOT 704 MHz
Peak output power (MW)	2.8	400	1.5	**1.2**
Frequency (MHz)	352.21	352.21	704.42	**704.42**
Gun	Diode gun	Filament	Diode gun	**Gridded Gun**
Pulse length (ms)	4	3.5	4	**3.5**
Rep. rate (Hz)	Up to 14	Up to 14	Up to 14	**Up to 14**
Maximum Beam Voltage (kV)	115	18	115	**50**
Efficiency at nominal output power	≥ 55%	> 65%	> 60%	**> 65%**
- 1dB Bandwidth (MHz)	≥ +/- 1	≥ +/- 3	≥ +/- 1	**≥ +/- 1**
Gain (dB)	≥ 40	>15	≥ 40	**≥ 20**

Acknowledgements

Thank you to RF Group at ESS for support and content

Eric Montesinos and Olivier Brunner, CERN

Staff at Uppsala University