The ESS RF systems and the plans for new developments

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Continuous Wave and High Average Power RF Workshop 2014
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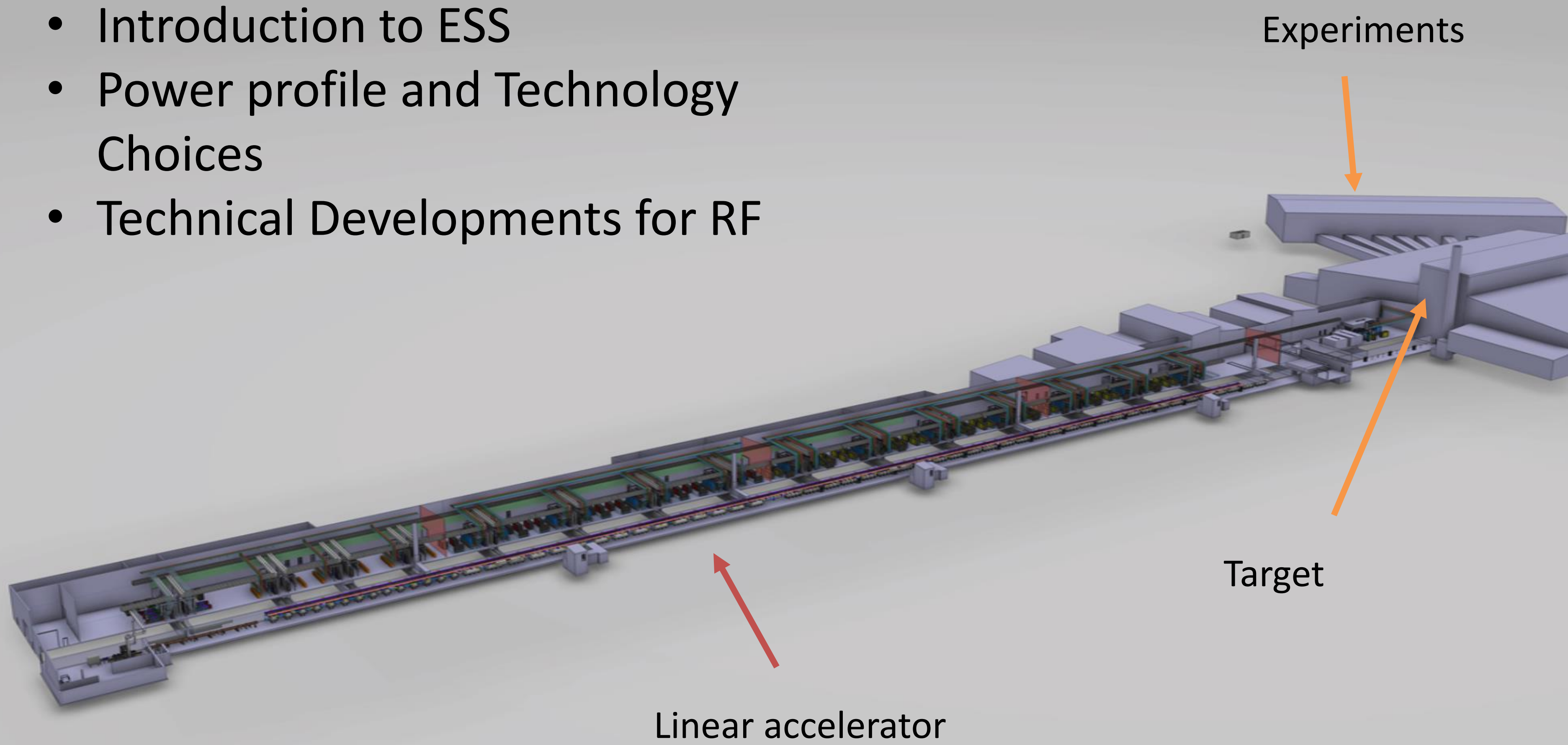
Agenda

- Introduction to ESS
- Power profile and Technology Choices
- Technical Developments for RF



Overview

- The European Spallation Source (ESS) will house the most powerful proton linac ever built.
  - The average beam power is five times greater than SNS.
  - The peak beam power will be over seven times greater than SNS
- The linac will require over 150 individual high power RF sources
- **We expect to spend over 200 M€ on the RF system alone**

Neutron Spallation Sources

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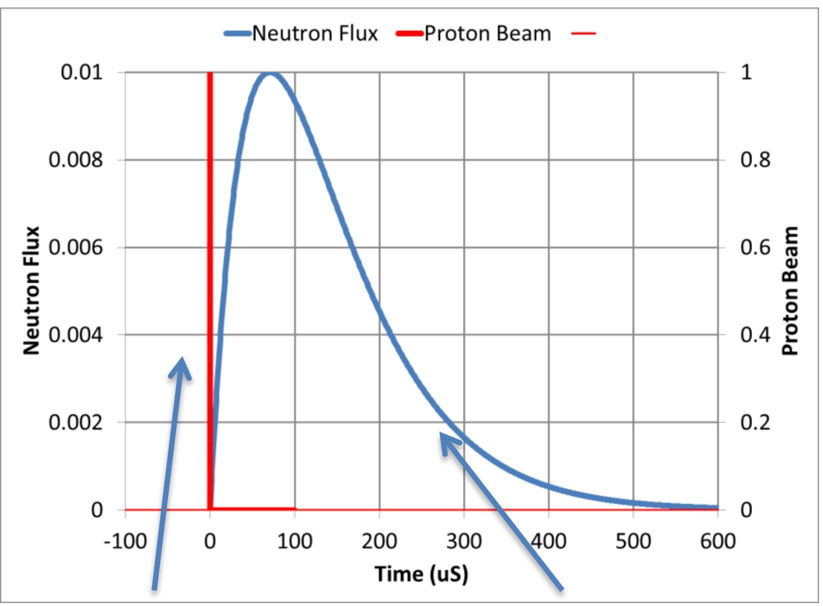
Short Pulse Concept

- Protons stored in circular accumulator
- Accumulator ring of 300 m = 1 μs
- Neutrons cooled in moderator following impact on target
- Neutron time constant = few 100 μs
- Short pulse at ESS power would destroy target or a 100 μs ring would be around 30 km

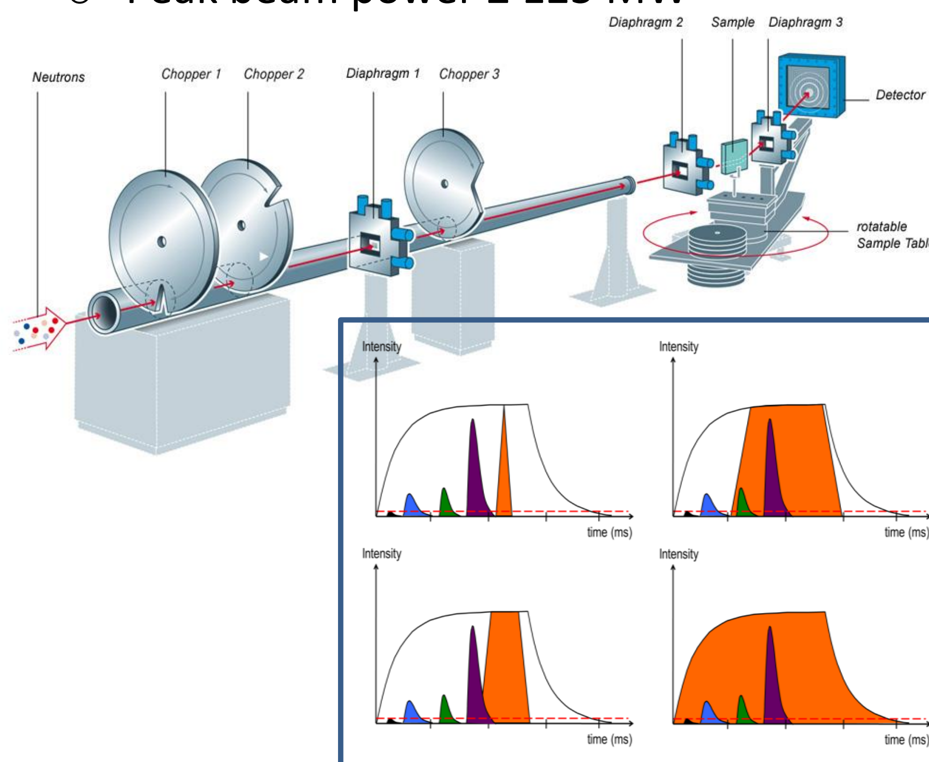


Proton Pulse

Neutron Output

Long Pulse Concept

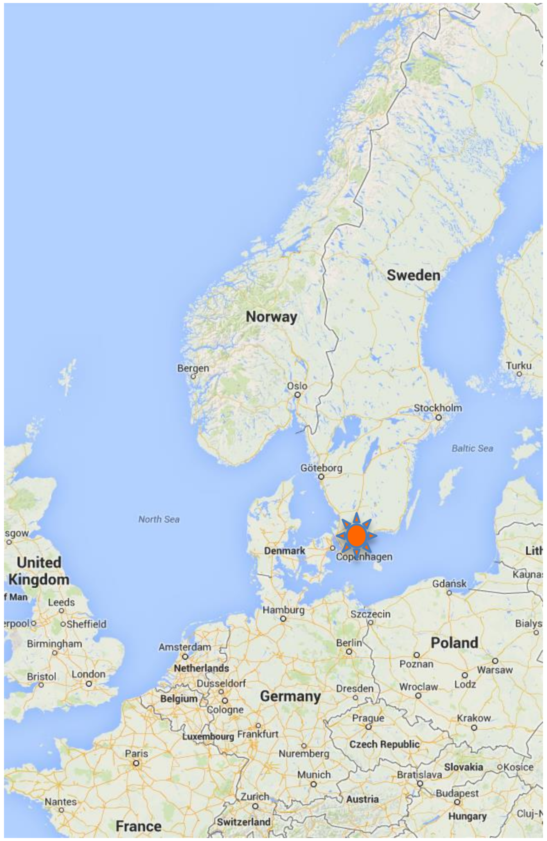
- No accumulator
- Neutrons still cooled in moderator following impact on target
- Choppers and long beam lines provide energy measurement
- Peak beam power ≤ 125 MW



The European Spallation Source

ESS is a

- long-pulse neutron spallation source based on a large linac
- Proton linac designed for 5 MW average power
- European project located in the southern part of Sweden



What is ESS?

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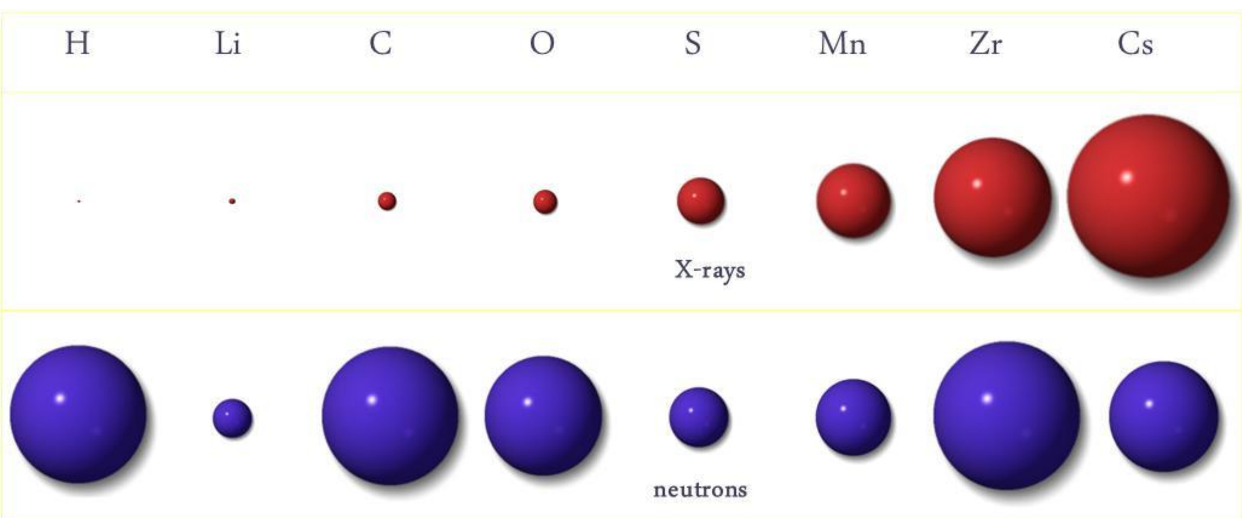
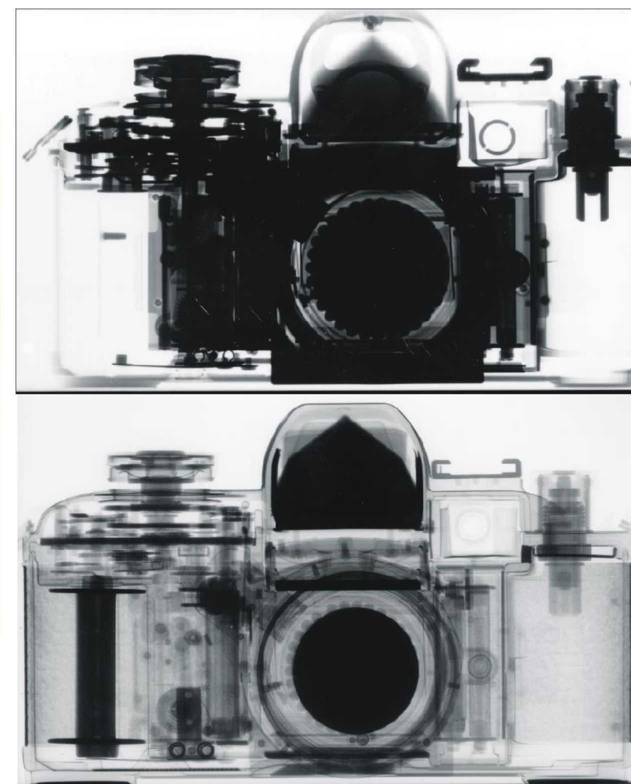
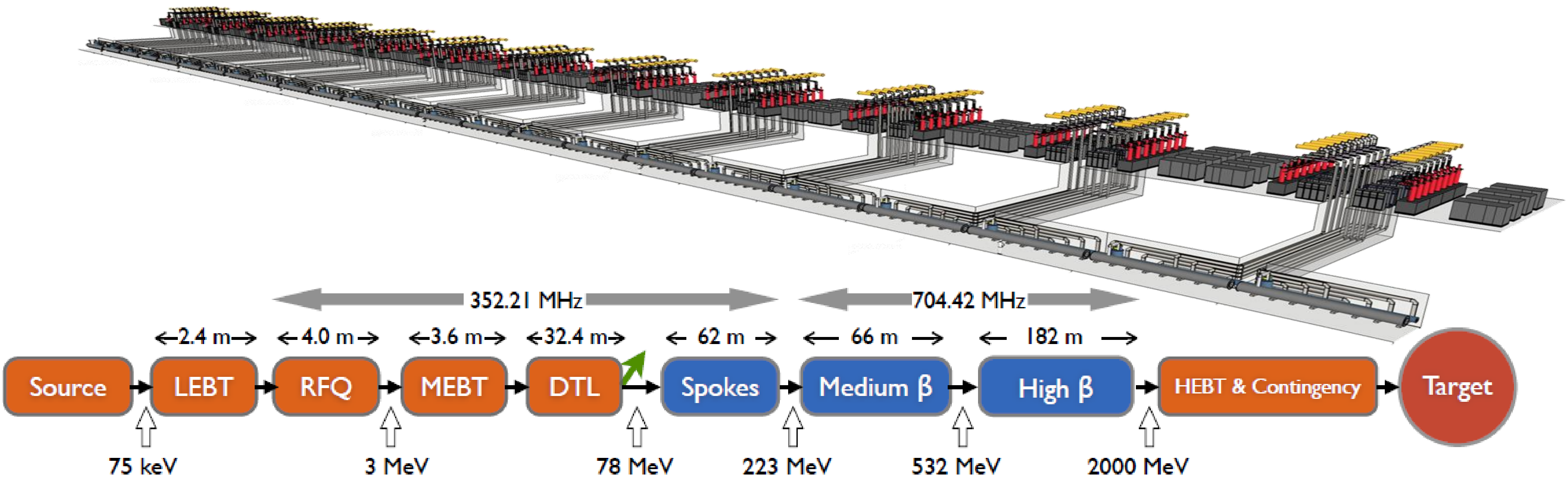
- ESS is a source for neutron scattering measurements.
- Neutron scattering offers a complementary view of matter





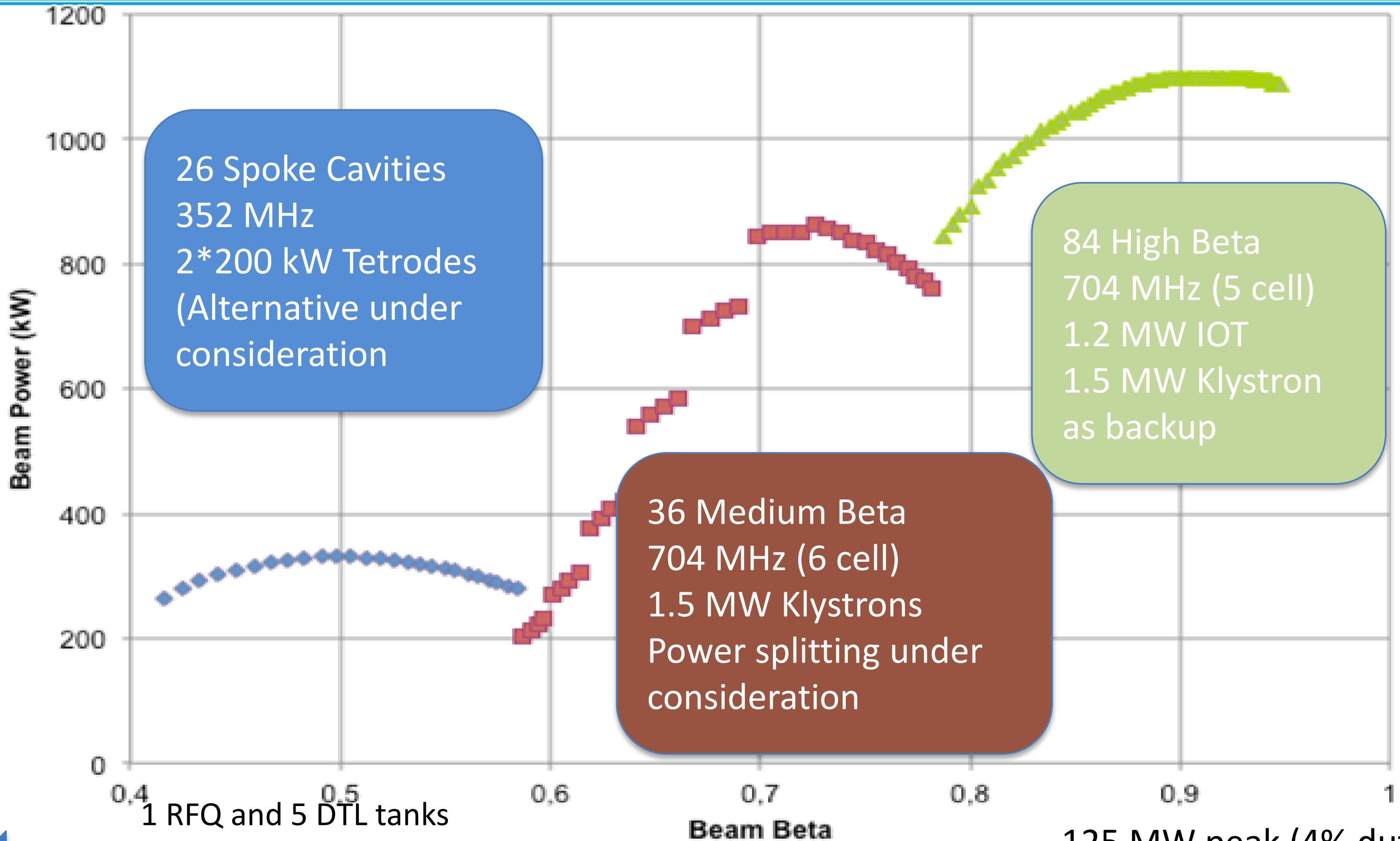
Linac Design Choices

- 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 (was 2.5 GeV) - 125 MW peak power.



The ESS Superconducting Power Profile

> 150 cavities/couplers



1 RFQ and 5 DTL tanks
352 MHz
2.8 MW Klystrons

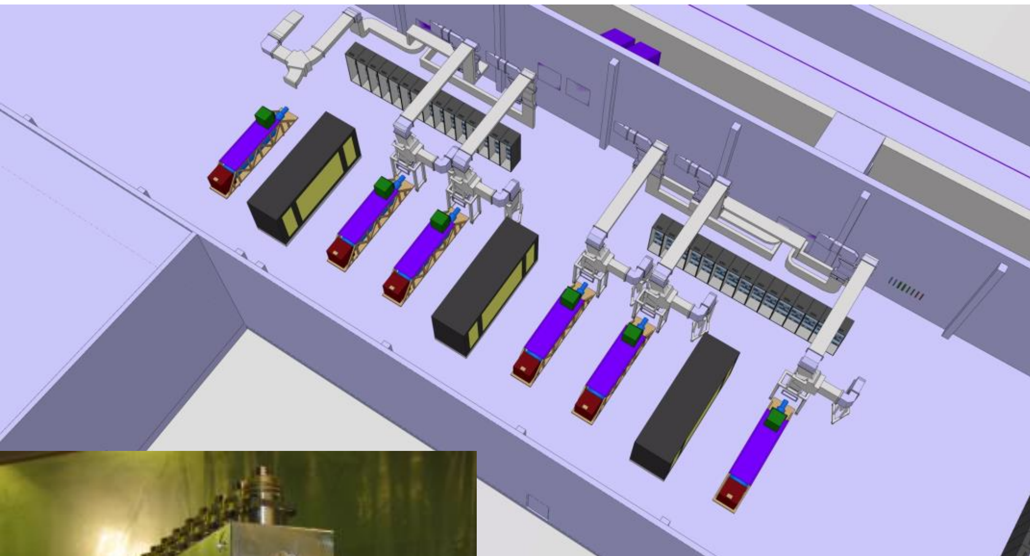
125 MW peak (4% duty)
5 MW average

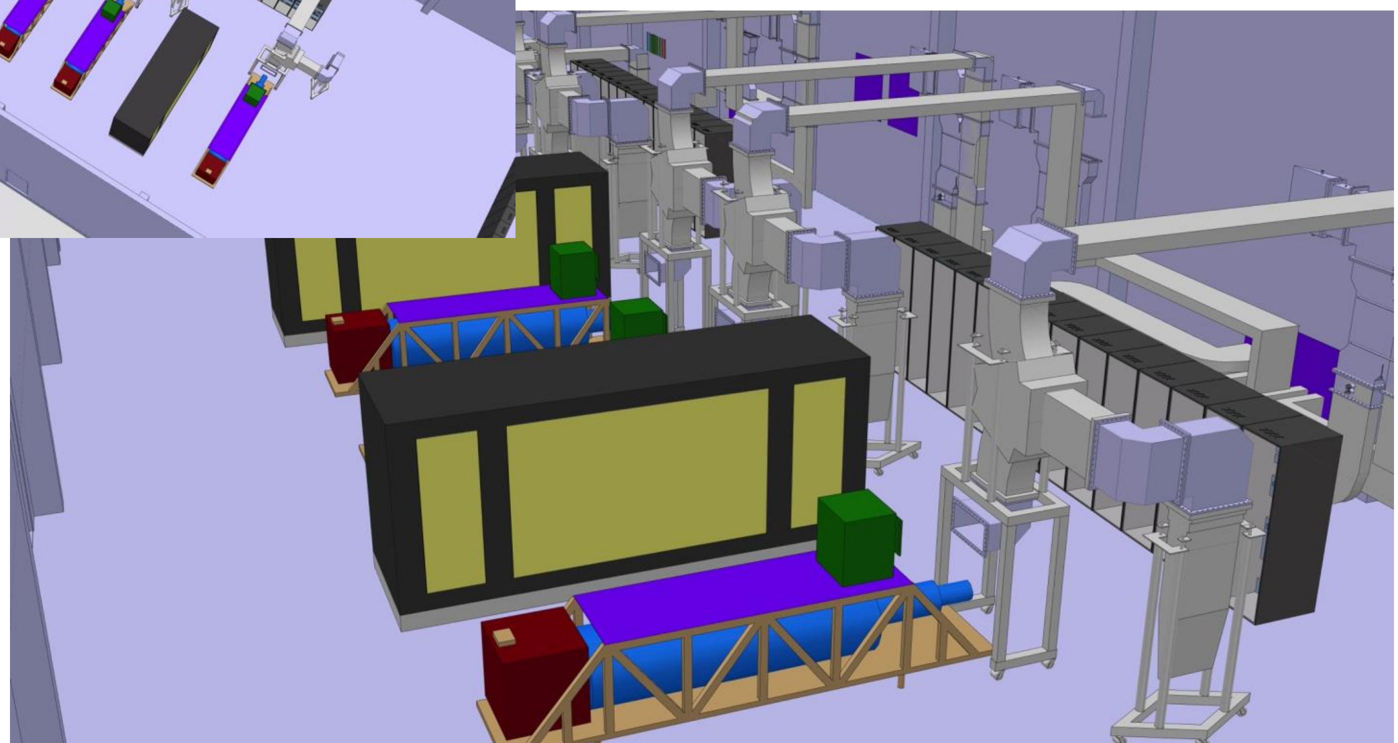
Power distribution for the RFQ and 5 Drift Tube Linacs

One 2.8 MW for RFQ
Five 2.8 MW klystrons for DLT

Power split to two couplers per DTL tank

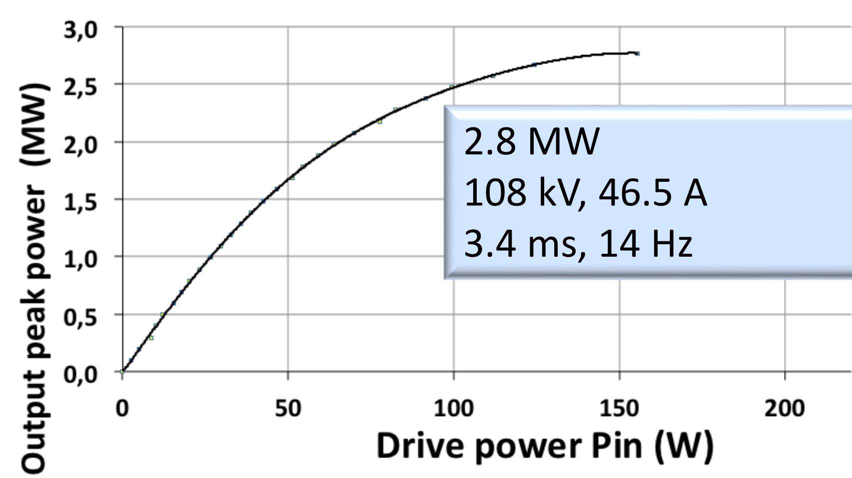
CPI	– VKP-8352B
Thales	– TH2179

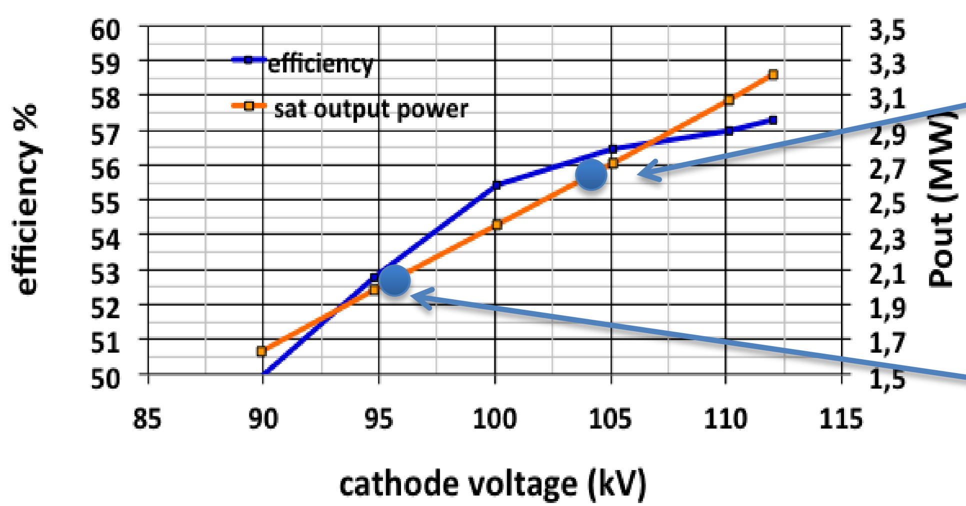




RFQ and DTL Power Source

Diode Gun – Constant Perveance
Operation at reduced voltage for improved efficiency





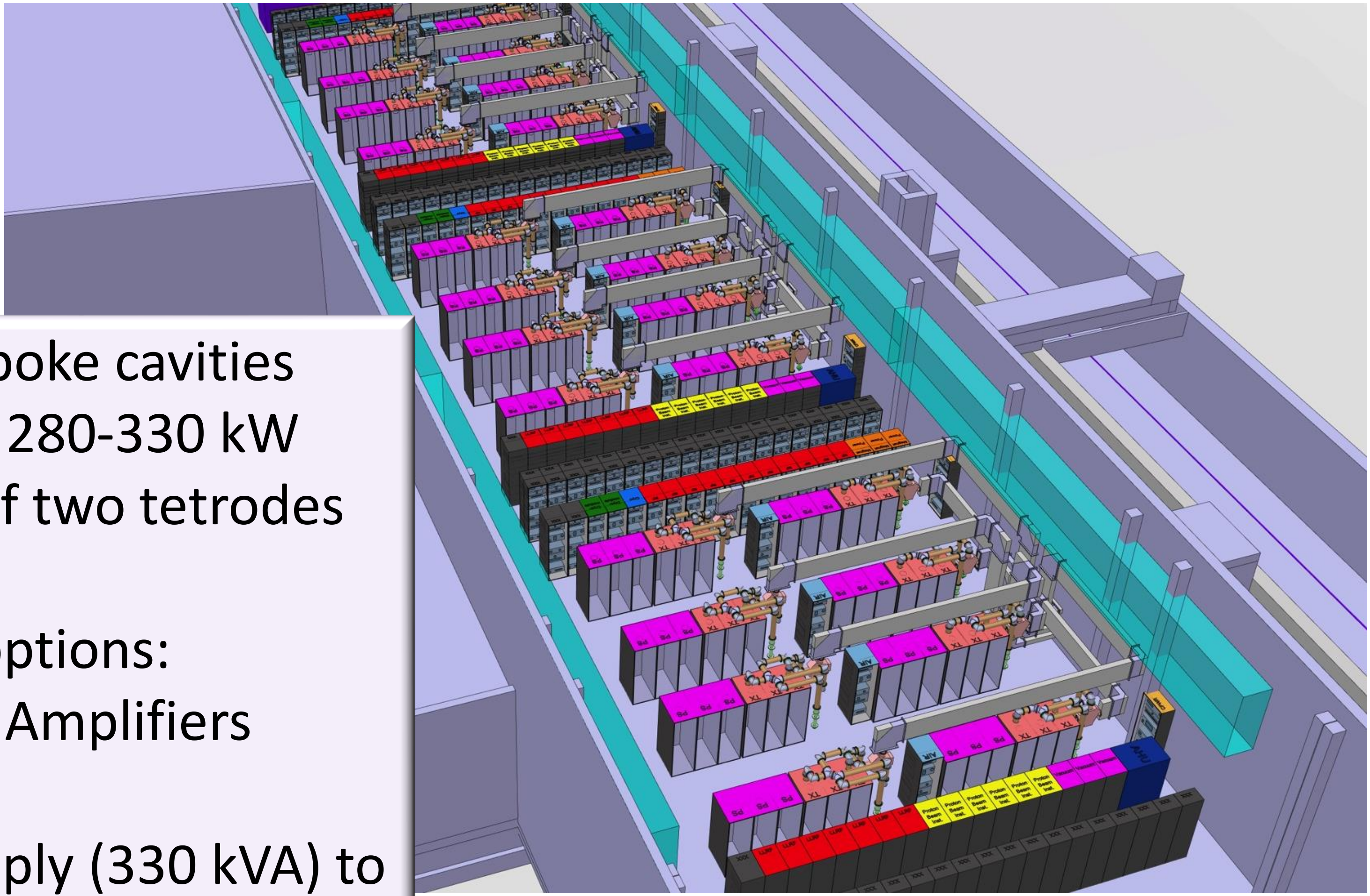
Courtesy of Thales

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



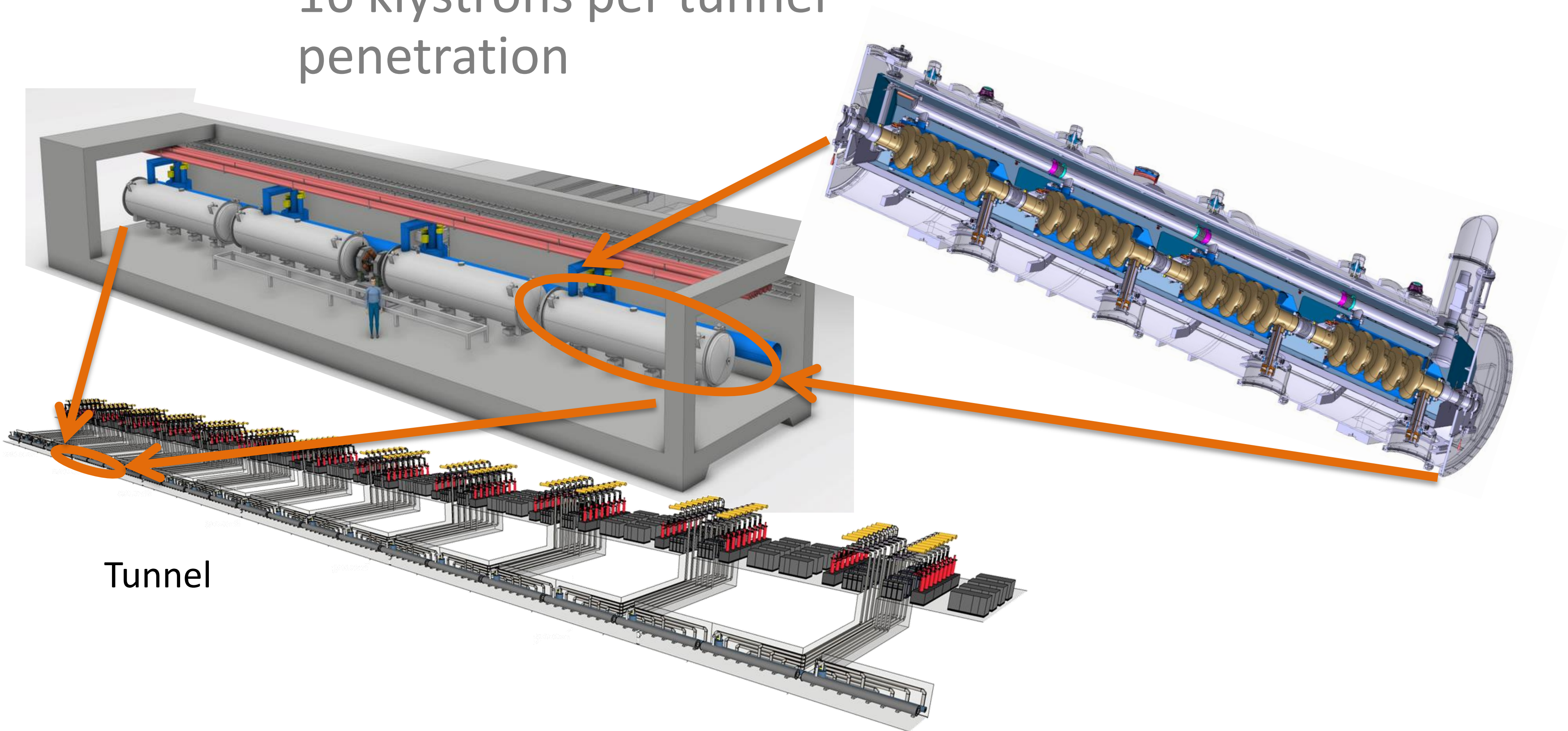
26 Double Spoke cavities
Power range 280-330 kW
Combination of two tetrodes

Other options:
Solid State Amplifiers

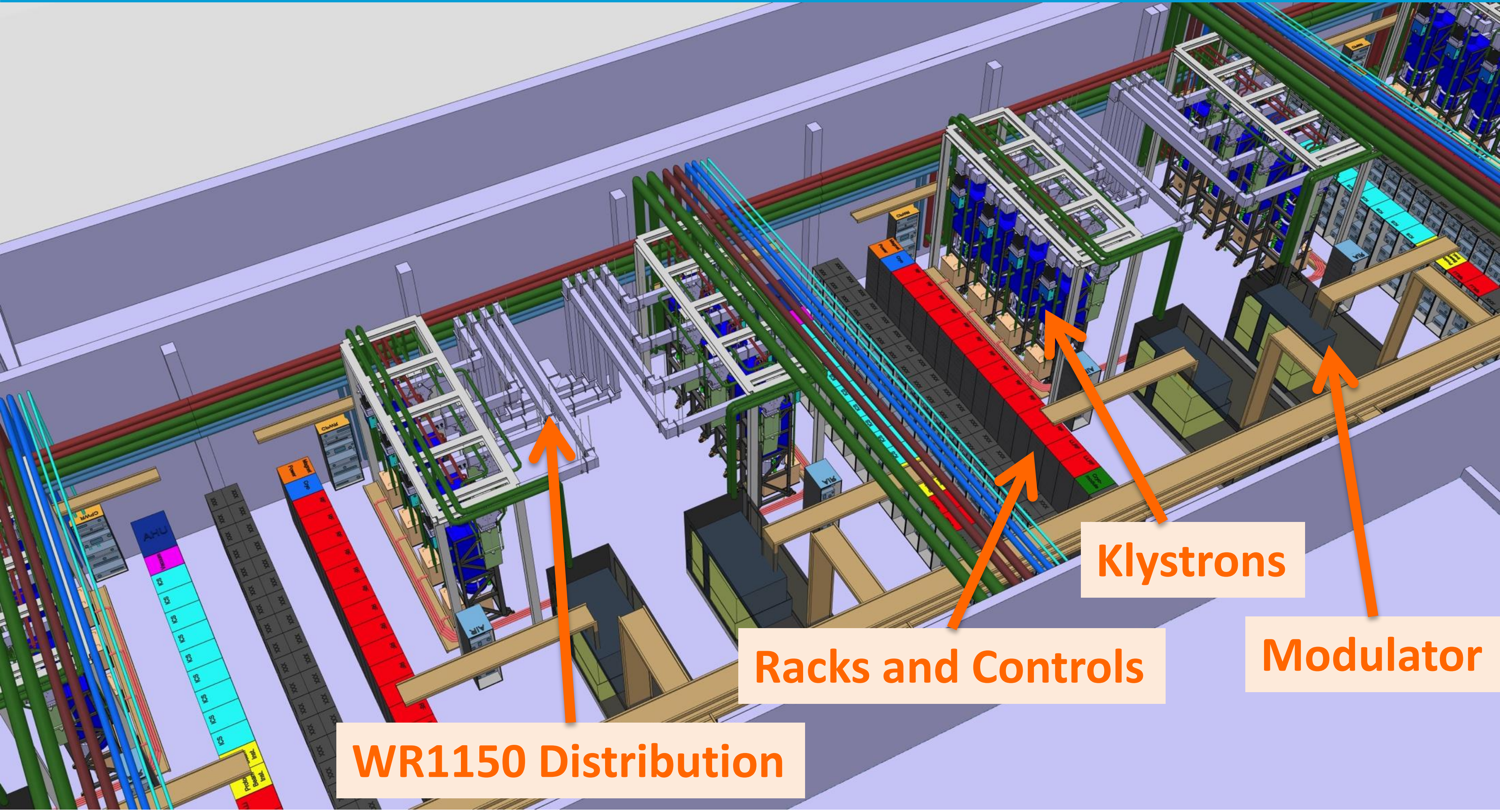
Large power supply (330 kVA) to supply 8 stations (16 tetrodes)

Elliptical (704 MHz) RF System Layout

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

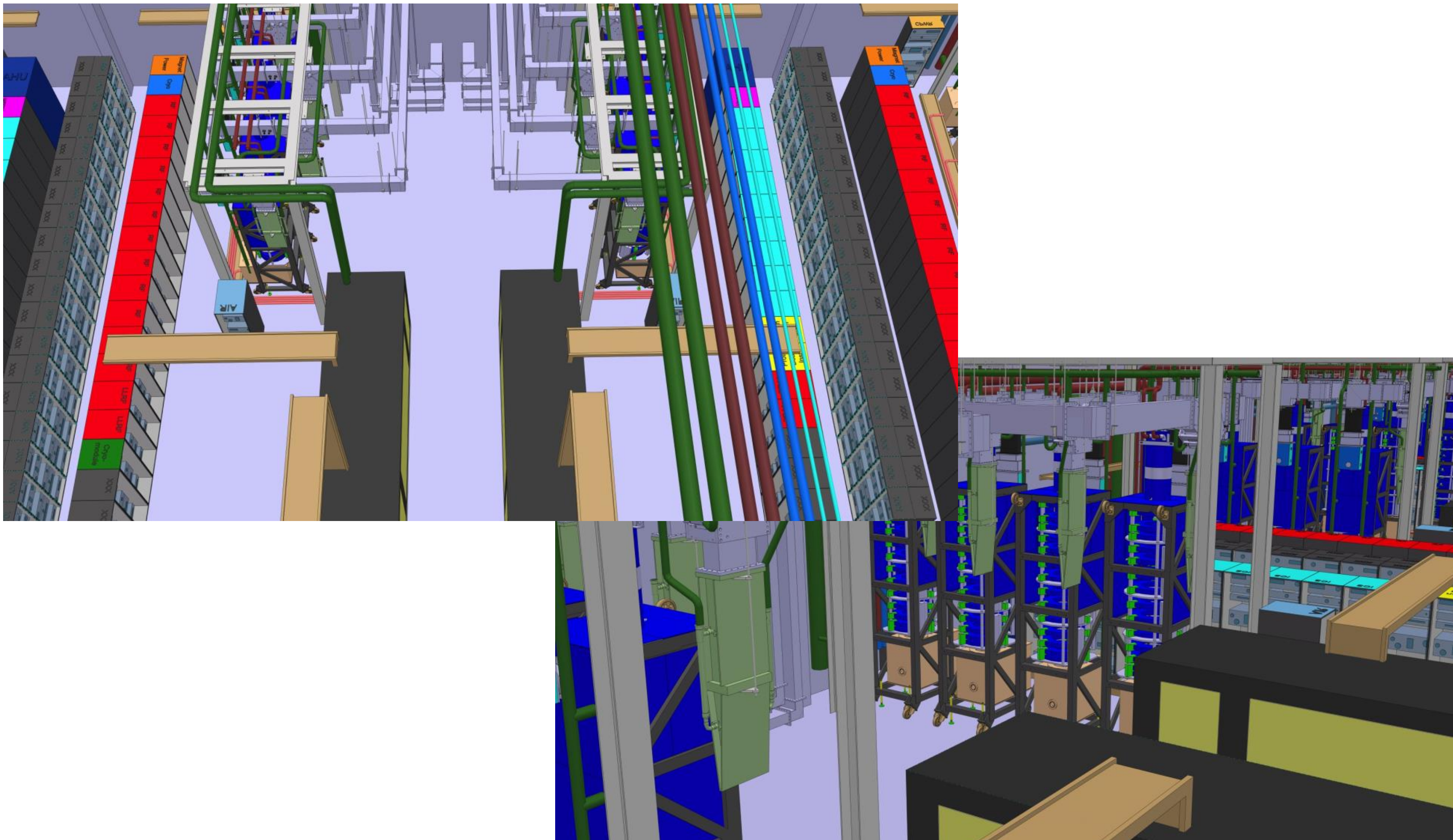


Elliptical (704 MHz) RF System Layout



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



Technical Developments

704 MHz Klystron to ESS Specifications

660 kVA Modulators

Super Power Multi-Beam IOT

704 MHz Klystron (Thales) factory tests

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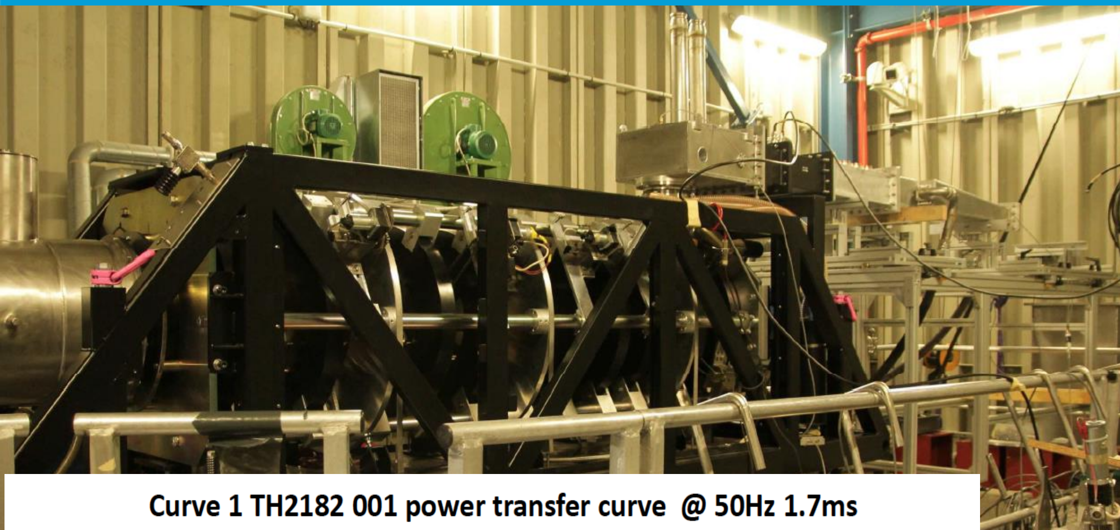
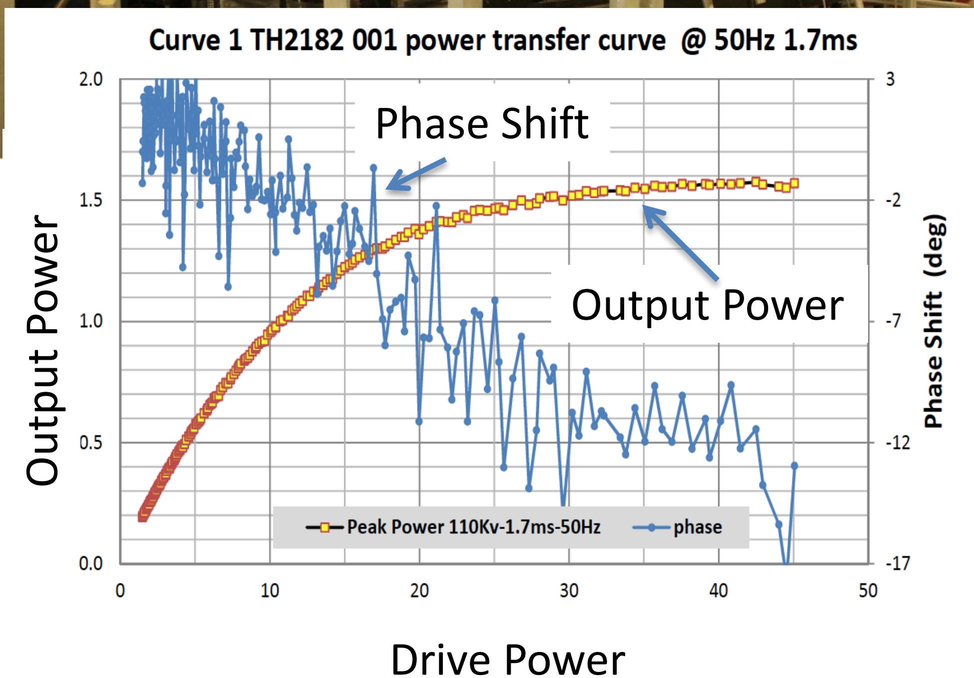
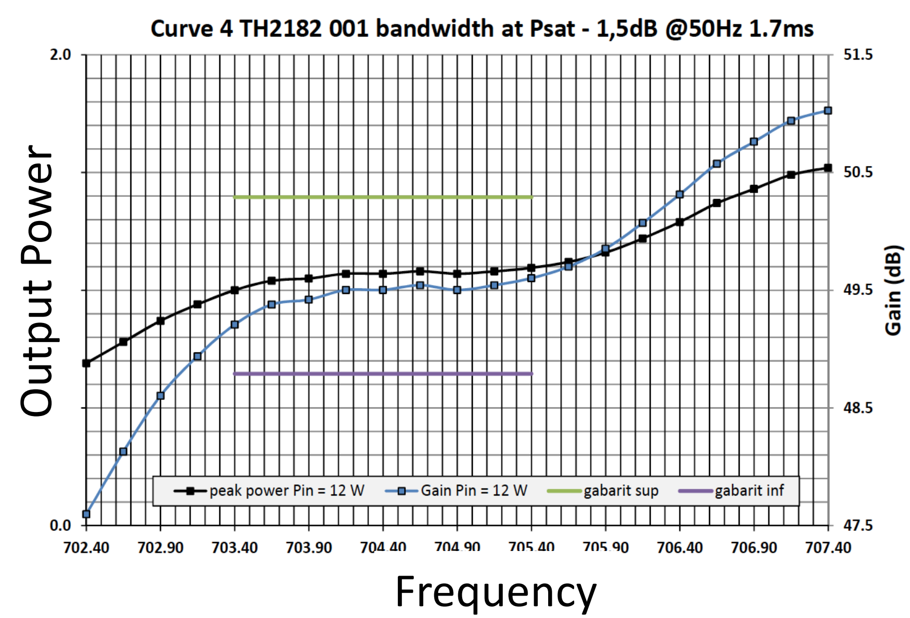


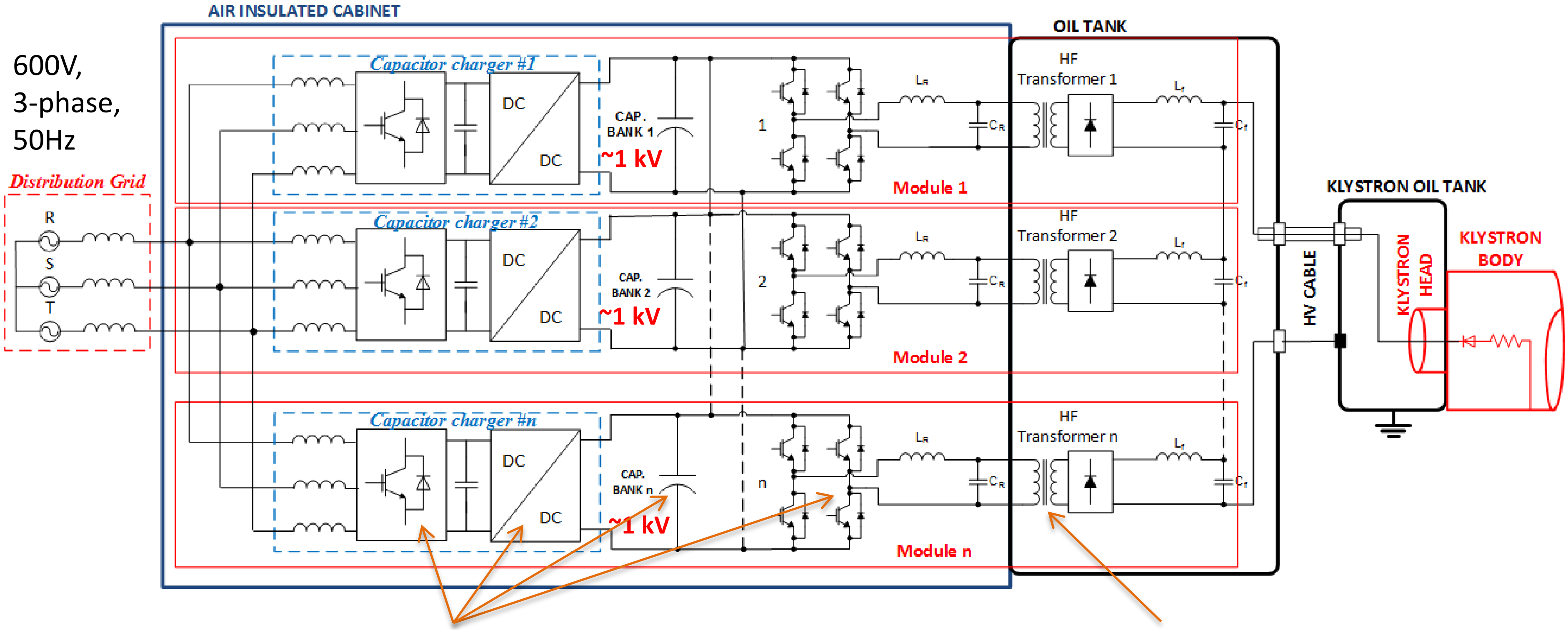
Meets RF Specifications

Proof of design





Resonant Multi-Level (RML) topology

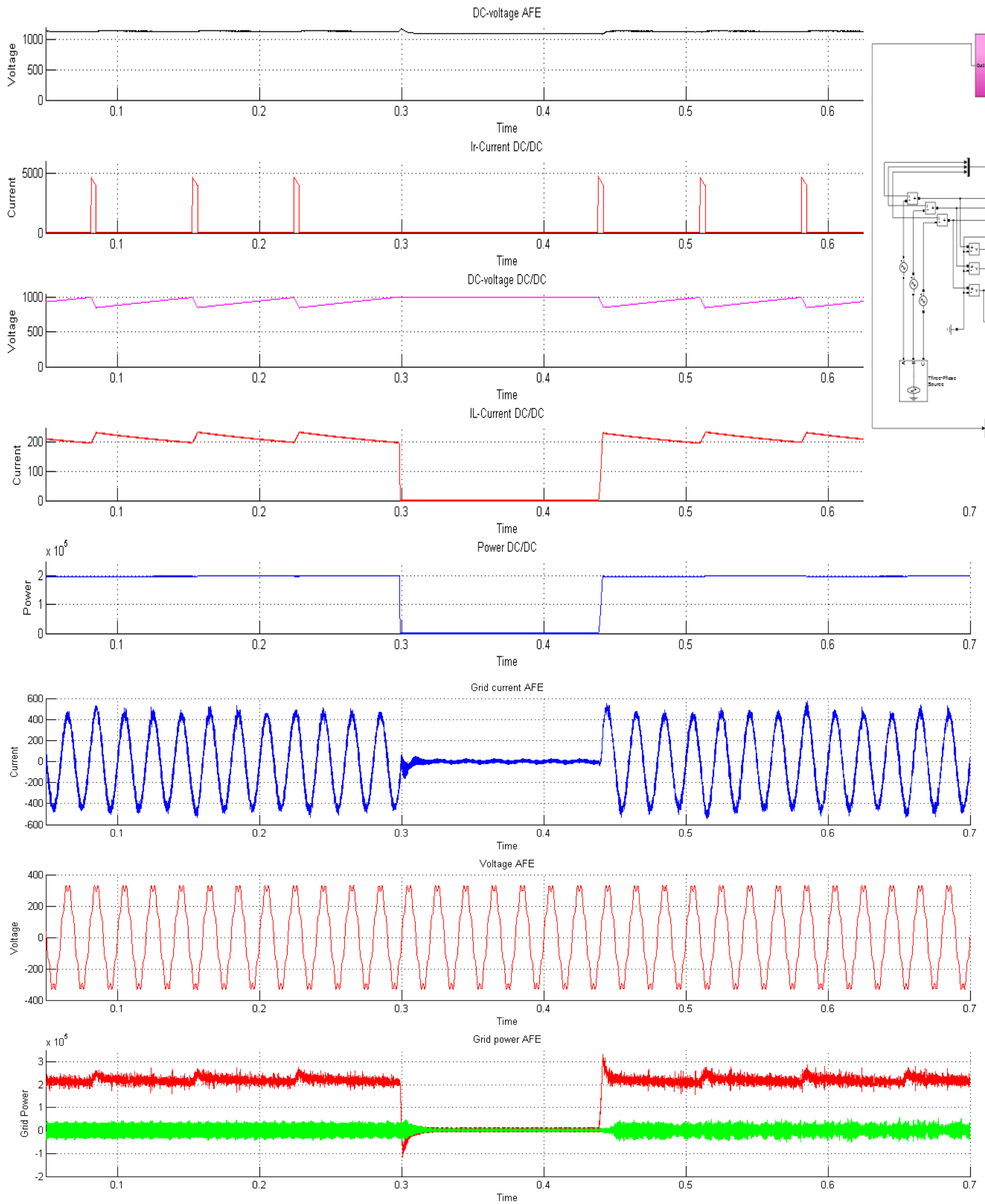


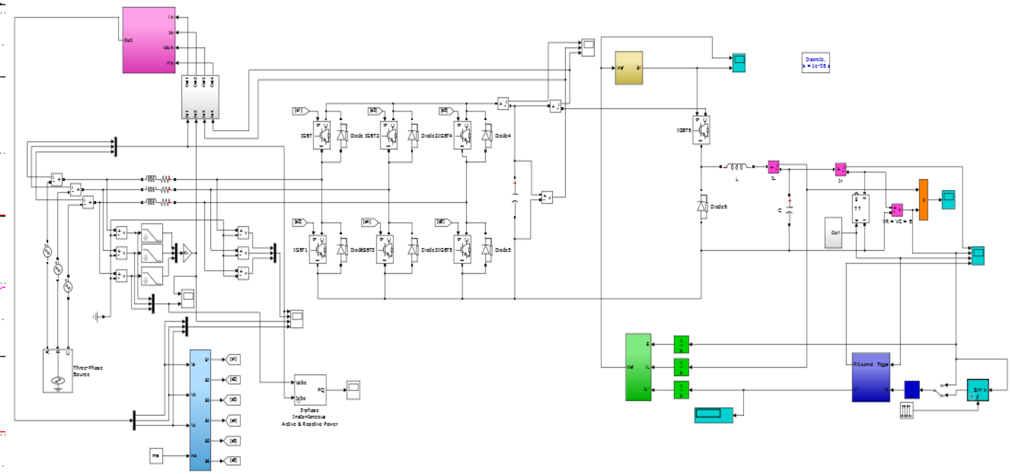
Keypoints:

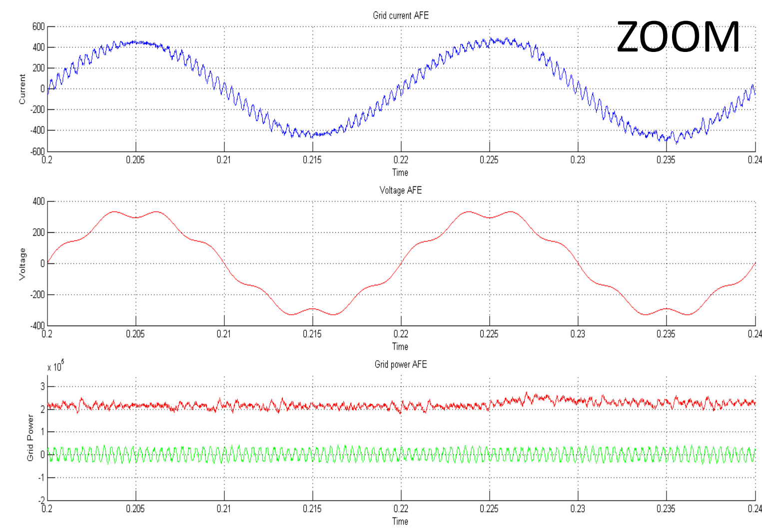
- Lower cost due to usage of standard LV components where possible;
- Reduced footprint/volume due to minimal sub-systems count;
- Compatible with PULSED and CW operations and with different types of RF amplifiers (Klystrons, IOT's, tetrodes, etc.);
- High efficiency (~94%);
- Excellent AC grid power quality (flicker-free, sinusoidal current absorption, unitary power factor);

Courtesy of Carlos Martins

Simulation Results: AC grid front end (1 module)







An RF Source for a Proton Linac

- 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

Klystron is a good match

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

ESS will be a proton Linac based on superconducting cavities

But…

An RF Source for a Proton Linac

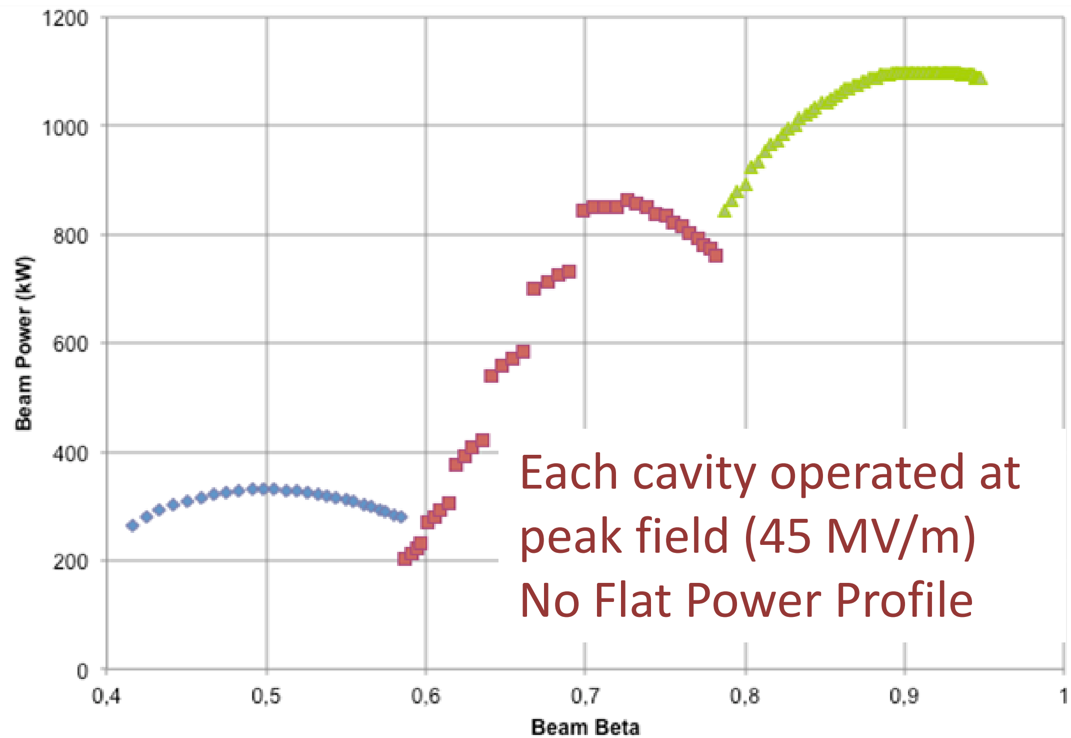
- SC cavities are difficult to manufacture
- Cell structure designed for one beam velocity
- Power profile shaped by transit time effects
- Strong individual Lorentz detuning
  - Short Cavity strings – lower power
  - One amplifier per cavity

Operation below saturation is inefficient
Operation point below saturation for regulation reduce actual efficiency

Actual efficiency ≤ 43 %

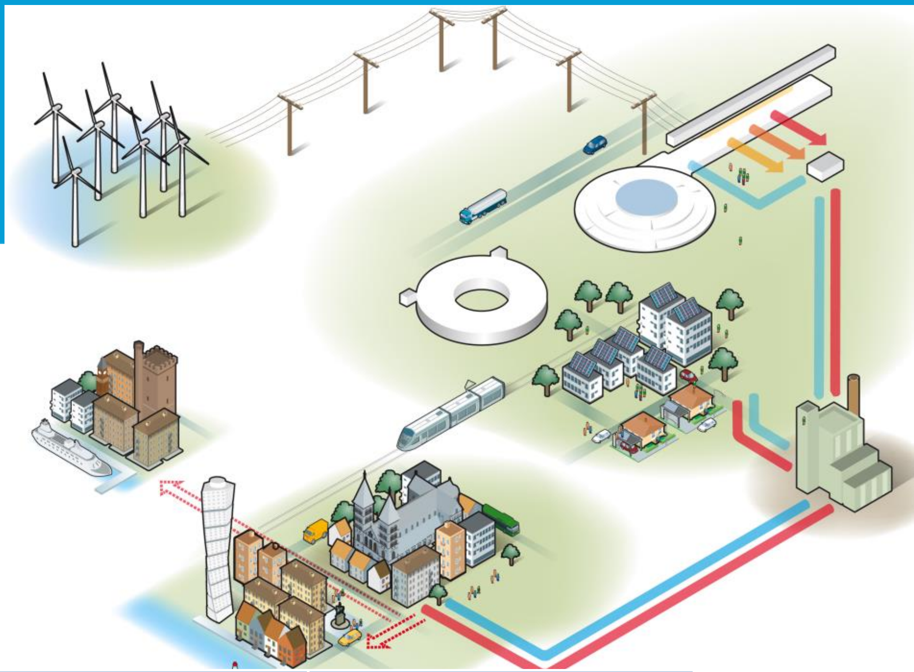
Investment in SC cavities has not been matched with investment in high efficiency RF sources

Power Profile



Where next?

The ESS Requirement



Carbon Neutral

Innovative

Green

Time to develop Super Power IOT

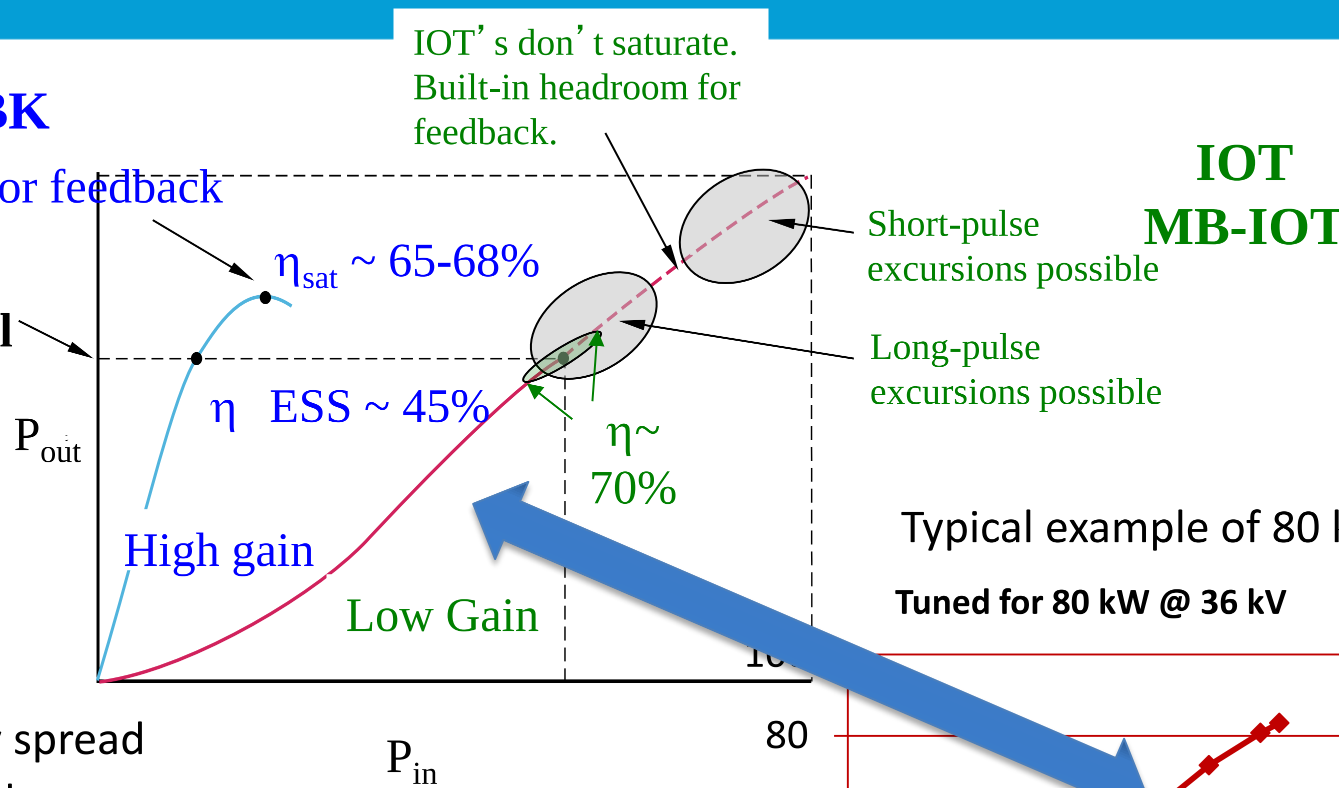
Accelerating Structure	Freq. (MHz)	Quantity	Max Power (kW)
RFQ, DTL	352	6	2200**
Spoke	352	26	240**
Elliptical Medium Beta	704	36	800**
Elliptical High Beta	704	84	1200**

High beta amplifier decision not before 2017/18

** Plus overhead for control

The Performance Comparison

Klystron/MBK

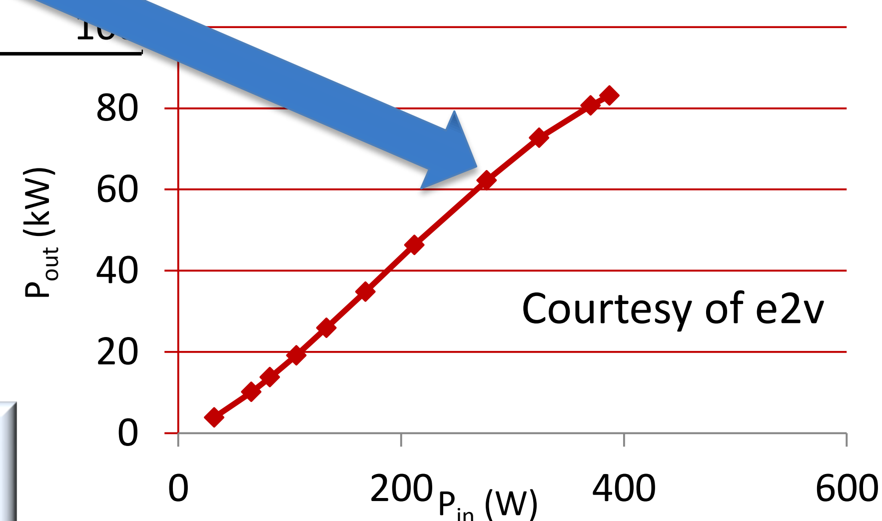


IOT
MB-IOT

Courtesy of CPI

Typical example of 80 kW cw IOT

Tuned for 80 kW @ 36 kV



Reduced velocity spread compared to klystrons
- Higher efficiency

No pulsed high voltage
- Cheaper modulator

Klystrons: Back-off for feedback cost 30%
IOTs: Operate close to max efficiency

IOT Options

- Combine ‘low power’ single beam IOTs by combining output
  - (for example Diamond and ALBA)
  - High number of IOTs for high power
  - More auxiliary supplies, cavities, magnets etc
- Single beam high power IOT
  - High voltage gun (> 90 kV)
  - Large cathode for low charge density
  - High voltage modulator design
- **Multi-Beam IOT**
  - **Reduced high voltage (< 50 kV)**
  - **Low space charge per beam**
  - **Very compact**
  - **High efficiency**

1.2 MW Multi-Beam IOT

Parameter		Comment
Frequency	704 MHz	
Maximum Power	1.2 MW	During pulse plus overhead for regulation
Pulse length	Up to 3.5 ms	Beam pulse 2.86 ms
Pulse repetition freq.	14 Hz	Duty factor 5%
Gain	> 20 dB	
Overhead margin	30%	Short duration only
High voltage	< 50 kV	No oil for the PSU nor the gun tank
Efficiency at 1.2 MW	≥ 65%	Design target
Design lifetime	50,000 hrs	Design target comparable with klystrons
Grid bias / Idle current	No idle current between pulses	May be gated
Prototypes required	Yes	Preference for separate manufacturing sites

1.2 MW Multi-Beam IOT

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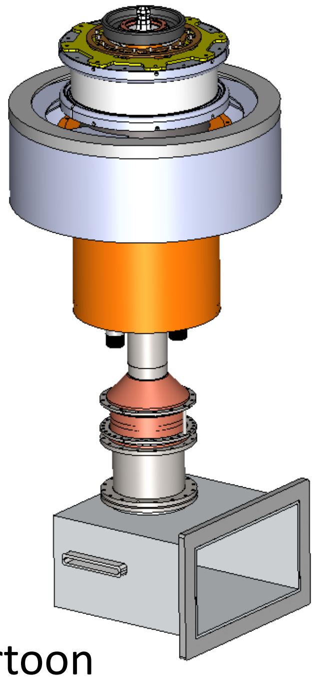
- High Beta Linac needs 84 sources plus spares
- Delivers 80% of the power to the beam
- Use of IOTs to reduce average power by 3 MW – 20 GWhr/yr
- Modulator cost is estimated to be 6-8 MEUR
- Installation to start post 2019
- Full installation by 2023/24 - Possible but tight!
- Possible spinoff – high power cw IOT for light sources?

- Technical risk is modest to high
- Klystrons considered as a backup technology
    - Cash risk – low project risk to project start
- Pre-determined go/no go for IOTs or klystron decision agreed
- Infrastructure (space, utilities, maintenance and serviceability) to allow for both IOTs and klystrons

1.2 MW Multi-Beam IOT

- ESS launched tender for IOT prototypes
- Tender replies received and evaluation near complete
  - Several technical implementations received
- Order expected in the next couple of weeks
- Delivery in 24 months
- Site acceptance at CERN followed by long term soak test

- Had hoped to present first work and pictures but can’t yet.



CPI Cartoon

Thank You