EUROPEAN SPALLATION SOURCE

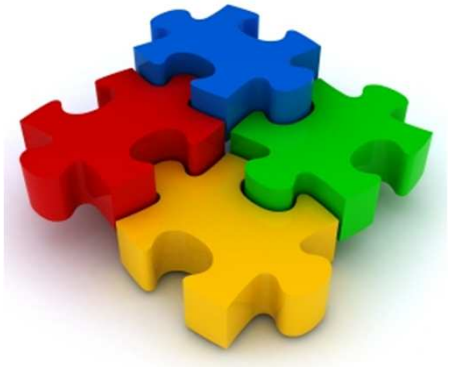
RF plans for ESS

Morten Jensen

ESLS-RF 2013 Berlin

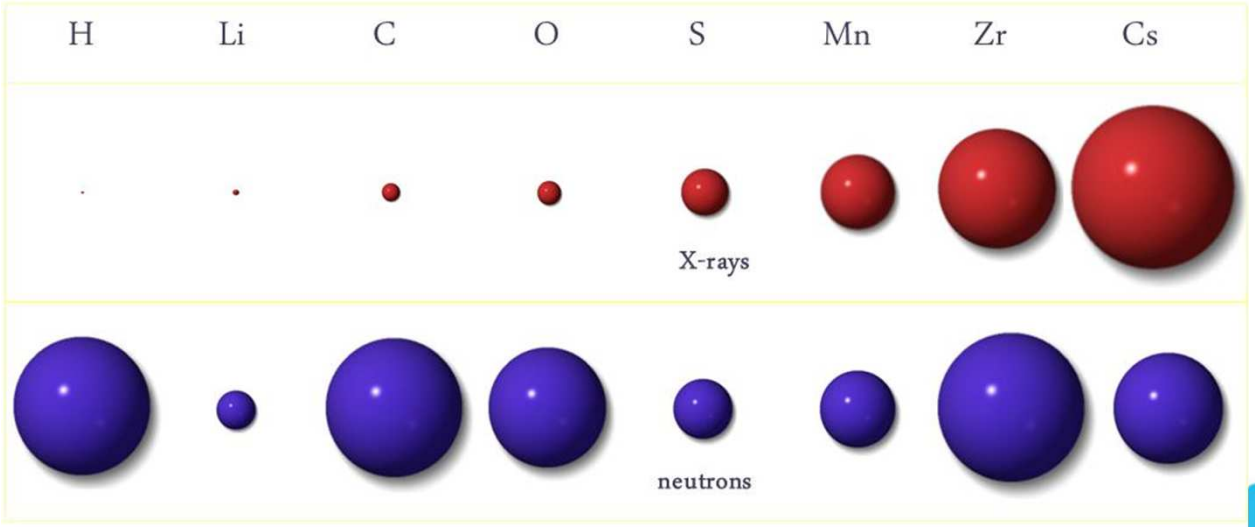
Overview

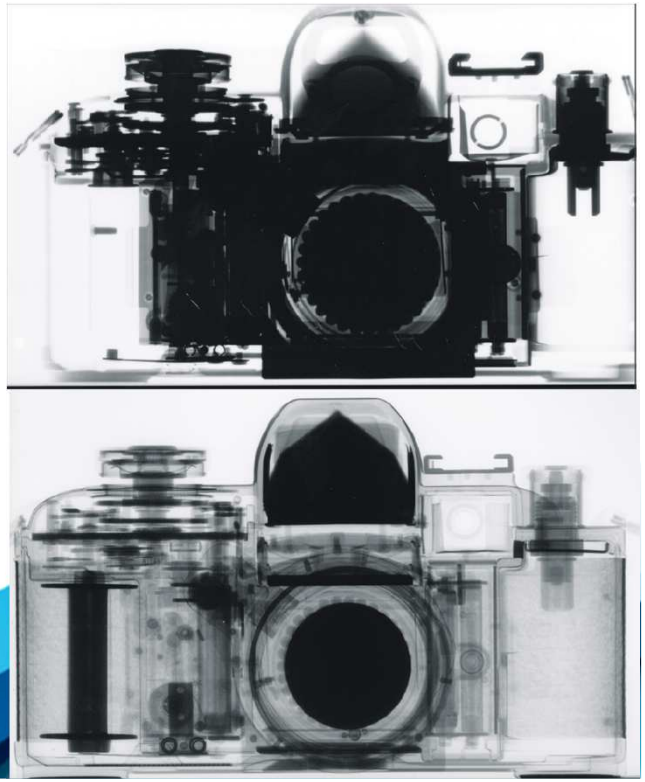
- The European Spallation Source (ESS) will house the most powerful proton linac ever built.
  - The average beam power will be 5 MW which is five times greater than SNS.
  - The peak beam power will be 125 MW which is over seven times greater than SNS
- The linac will require over 150 individual high power RF sources
- **We expect to spend over 200 M€ on the RF system alone**



What is ESS?

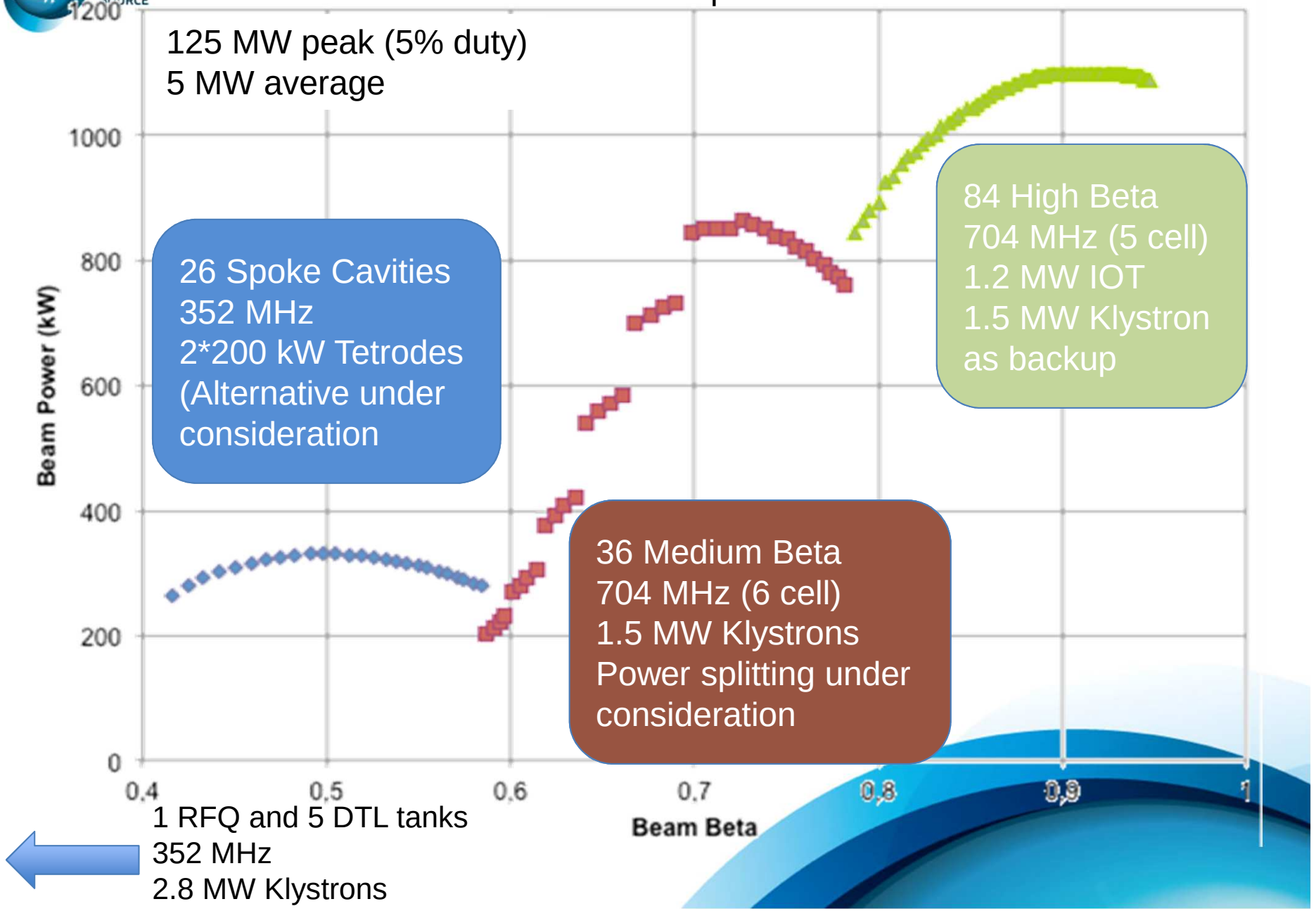
- ESS is a neutron spallation source for neutron scattering measurements.
- Neutron scattering offers a complementary view of matter





The ESS Superconducting Power Profile

> 150 cavities/couplers

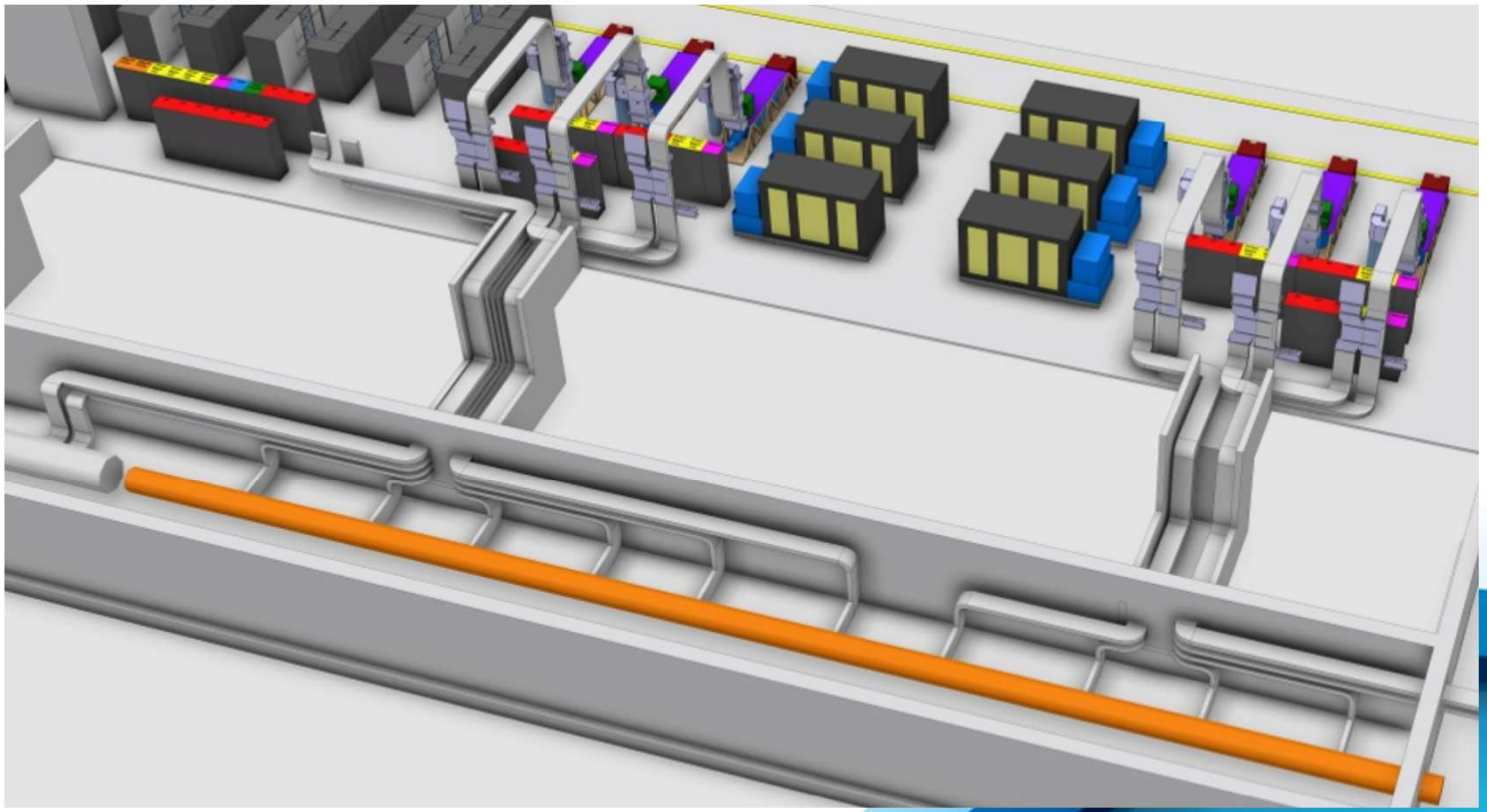


Power distribution for the 5 Drift Tube Linacs

Five 2.8 MW klystrons for DLT
One 2.8 MW for RFQ

Power split to two couplers per DTL tank

CPI	– VKP-8352B
Thales	– TH2179

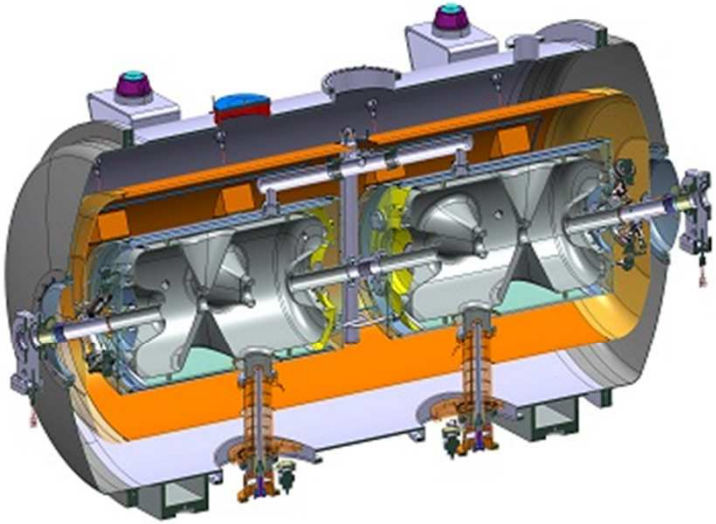


Spoke Cavities 352 MHz

Baseline solution:

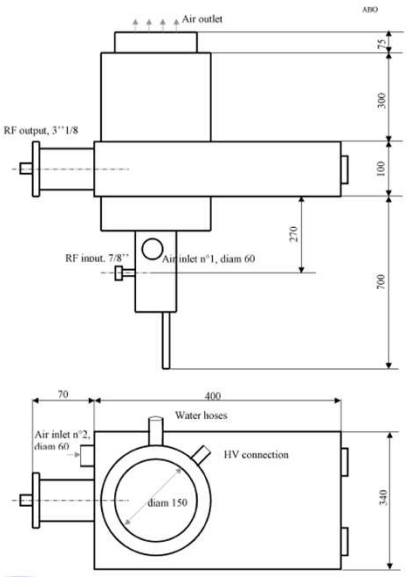
Combination of two 200 kW tetrodes

Currently one RF source per cavity



Tetrode TH595 and cavity Th18595 A at Thales

Tetrode TH595



Amplifier cavity TH 18595A

THALES

Courtesy of Yogi Rutambhara

Options being considered to reduce cost:

- Larger modulator for several RF sources
- Large klystron split for 2/4/6 cavities

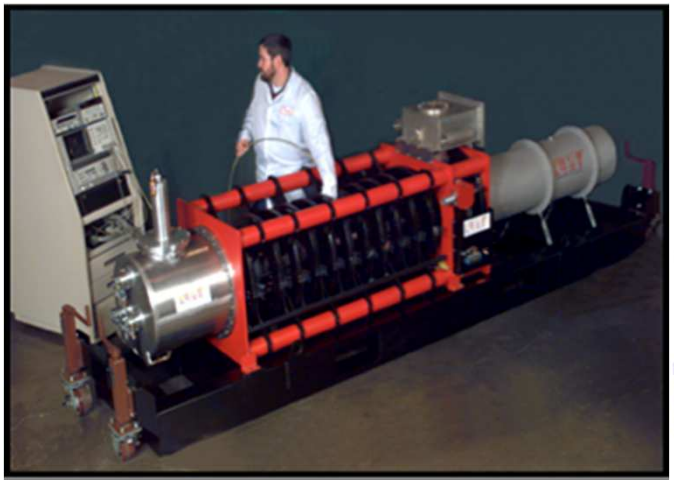
Amplifier Prototype ordered for FREIA Test Stand in Uppsala

Elliptical Cavities 704 MHz

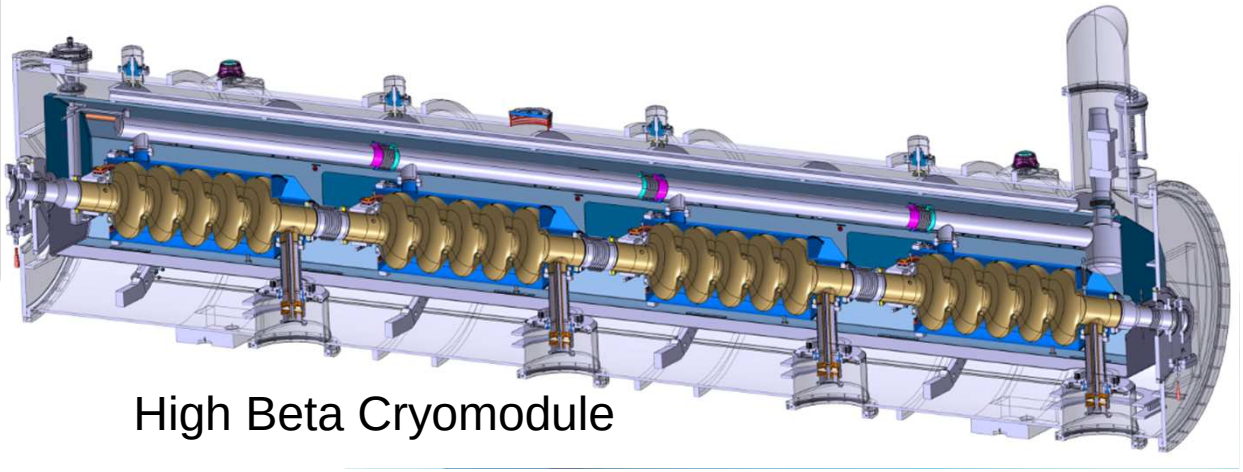
Baseline solution:

- ❖ (36+84) 1.5 MW klystrons
- ❖ Currently one RF source per cavity
- ✧ Possibility to feed >1 cavity per klystron
- ✧ Possible use of high KVA modulator

Suppliers include:
Thales, CPI and Toshiba



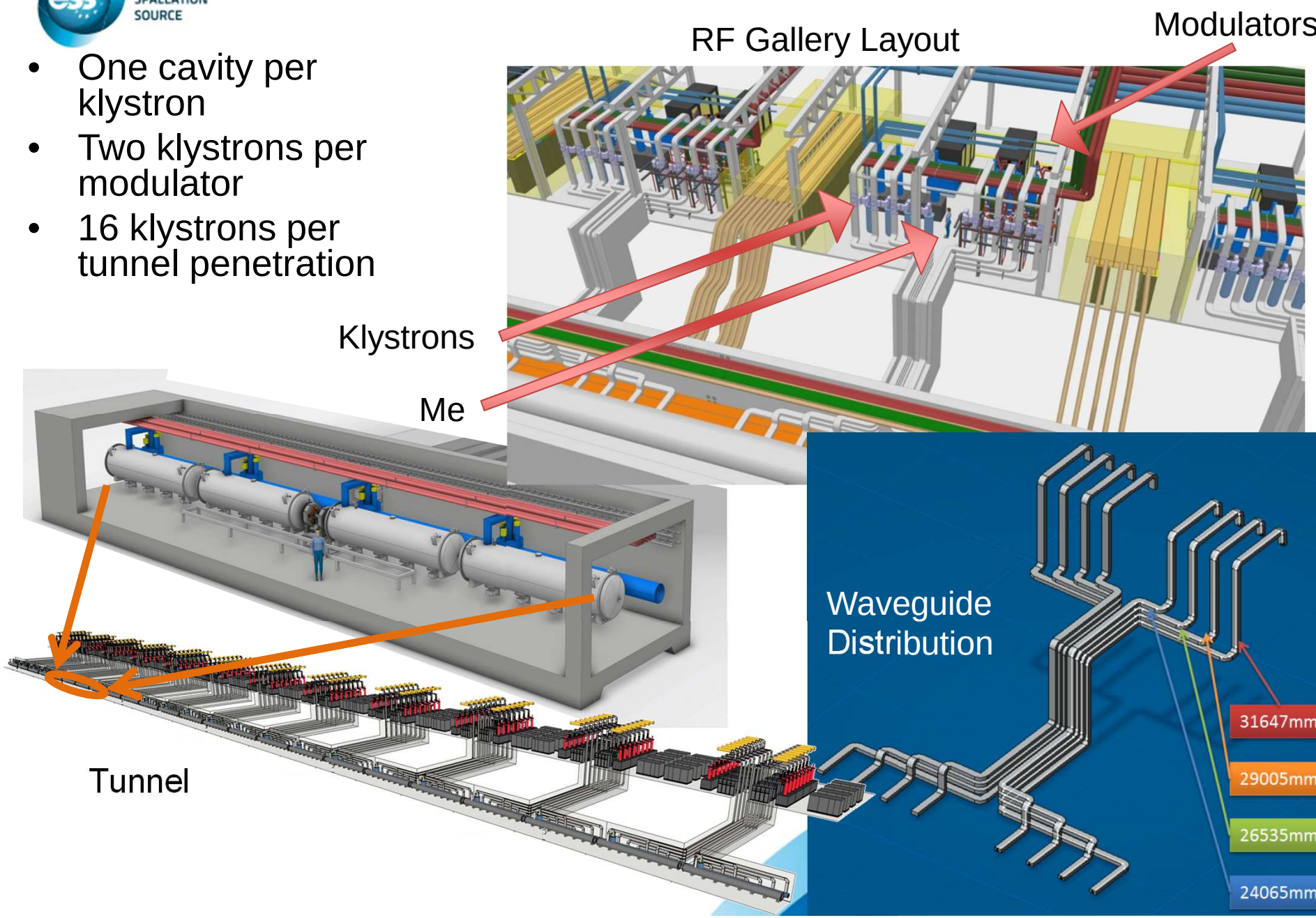
- 36 Medium Beta β_g = 0.67
  - 6 cell cavities
  - Maximum peak RF power = 800kW
- 84 High Beta β_g = = 0. 86
  - 5 cell cavities
  - Maximum peak RF power = 1100kW



High Beta Cryomodule

Elliptical (704 MHz) RF System Layout

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



The ESS Redesign

EUROPEAN SPALLATION SOURCE

Before November 2012

- Limited procurement time
- Modulator and Klystron Strategy

***** Buy Lots and Right Now!*****

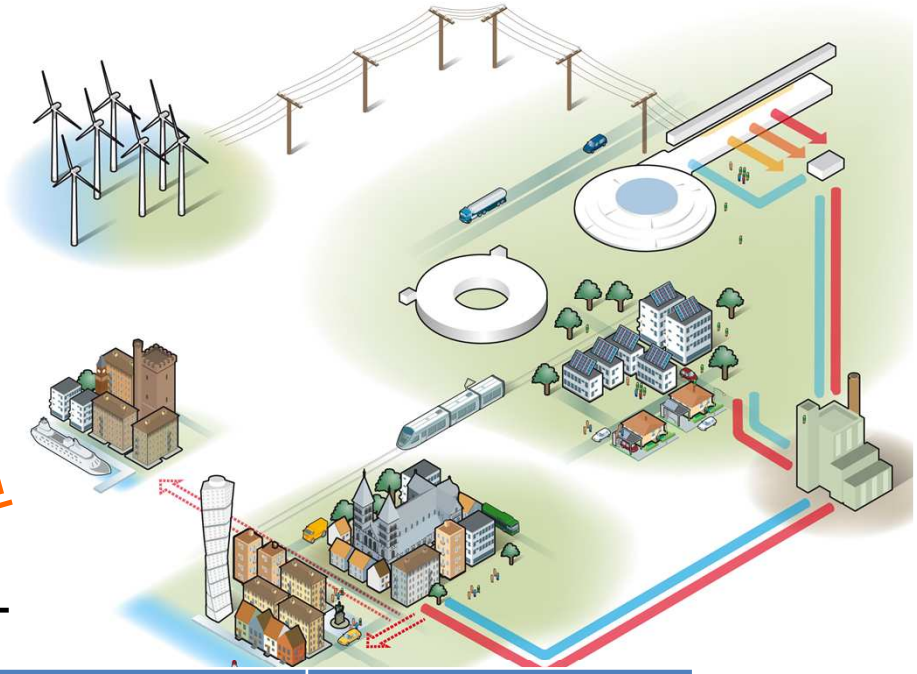
Current thinking

- Buy ‘standard’ klystrons for the Medium Beta
- Investigate IOTs for High Beta

Development Opportunity

Where next?

The ESS Requirement



Carbon Neutral

Innovative

Green

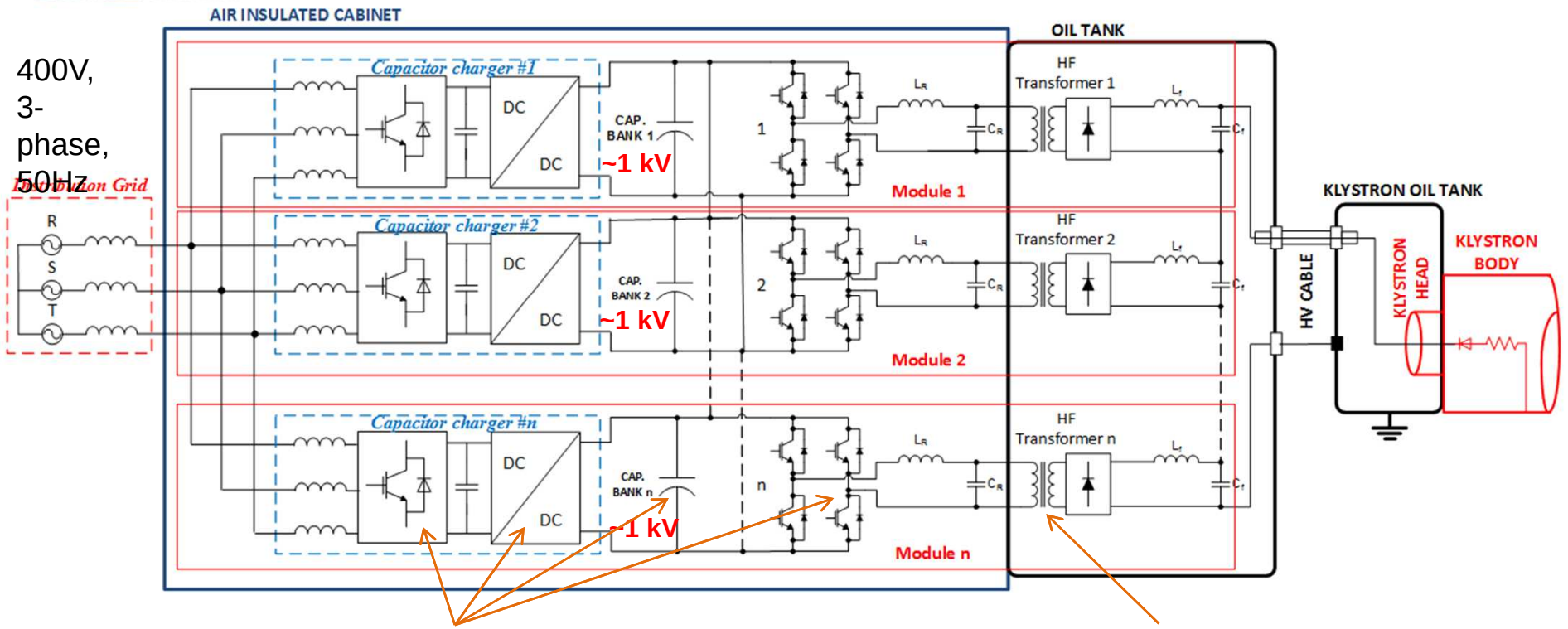
Time to develop Super Power IOT

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

** Plus overhead for control

Resonant Multi-Level (RML) topology



Standard "of-the-shelf" LV components

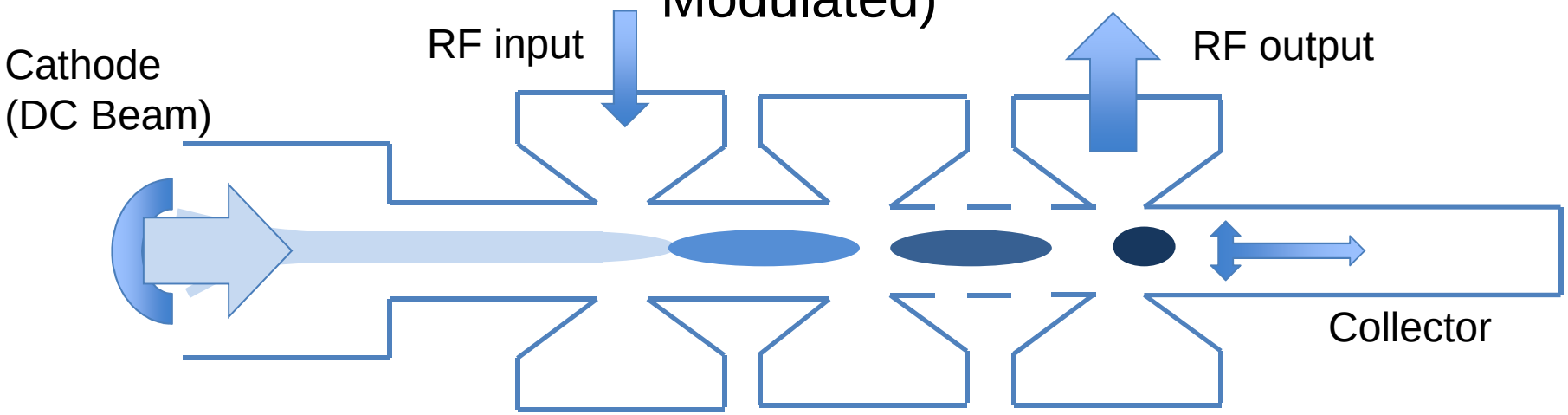
Special HV components & assembly

Keypoints:

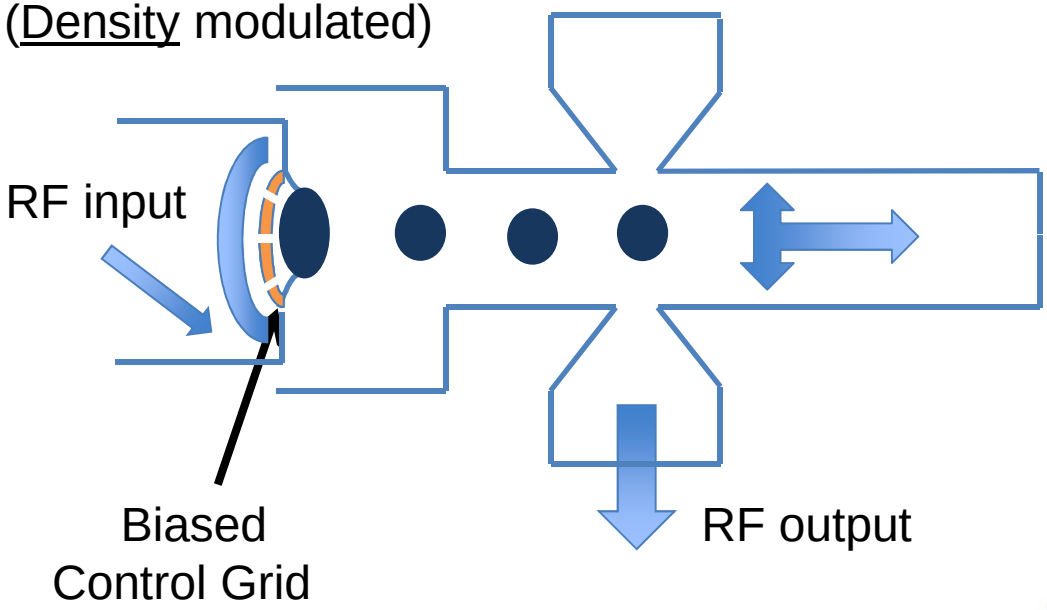
- Lower cost due to usage of standard LV components into a great extent;
- Reduced footprint/volume due to minimal sub-systems count;
- Compatible both with PULSED and CW operations and with different types of RF amplifiers (Klystrons, IOT's, tetrodes, etc.);
- Improved efficiency (~94%), due to minimal number of conversion stages in capacitor chargers;
- Excellent AC grid power quality (flicker-free, sinusoidal current absorption, unitary power factor);

Courtesy of Carlos Martins

Klystron (Velocity Modulated)



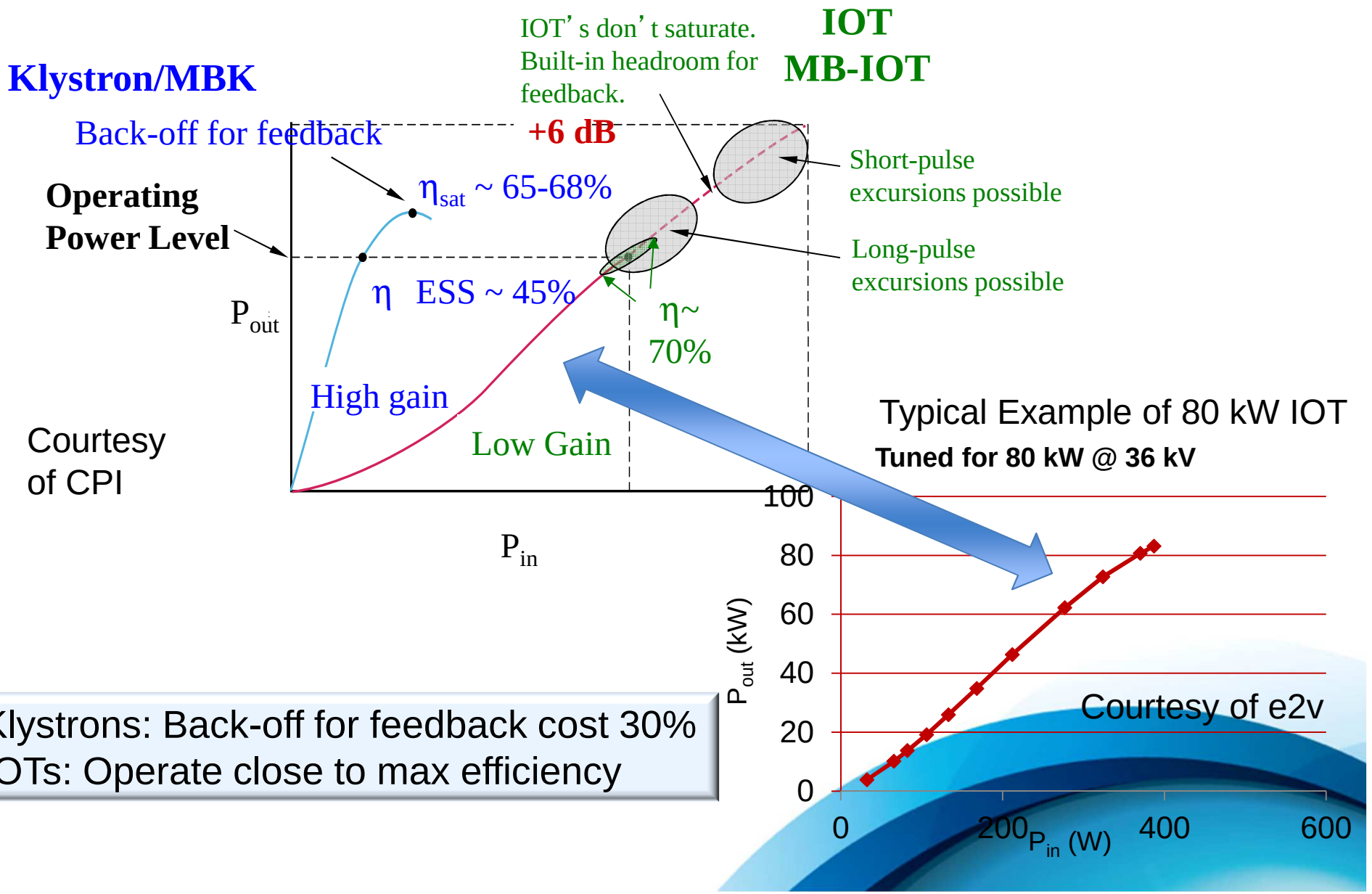
IOT
(Density modulated)



Reduced velocity spread
Higher efficiency

No pulsed high voltage
Cheaper modulator

The Performance Comparison



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

IOT Advantages

High Efficiency and Minimal Energy Consumption is Mandatory for ESS

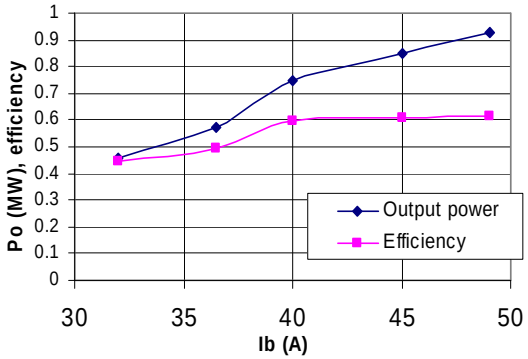
- Modulator Efficiency 90% to > 95%
- RF Efficiency 43% to > 60%
- Power Saving from High Beta section 3.3 MW
- Efficiency higher still at low current
- Heat from collectors can still be recovered
- Modulator capital cost is lower saving 6-10 M EUR
- Smaller form factor affecting space/cost of the building
- Lower voltage, no oil tanks

700 MHz HOM IOT Experience

CPI

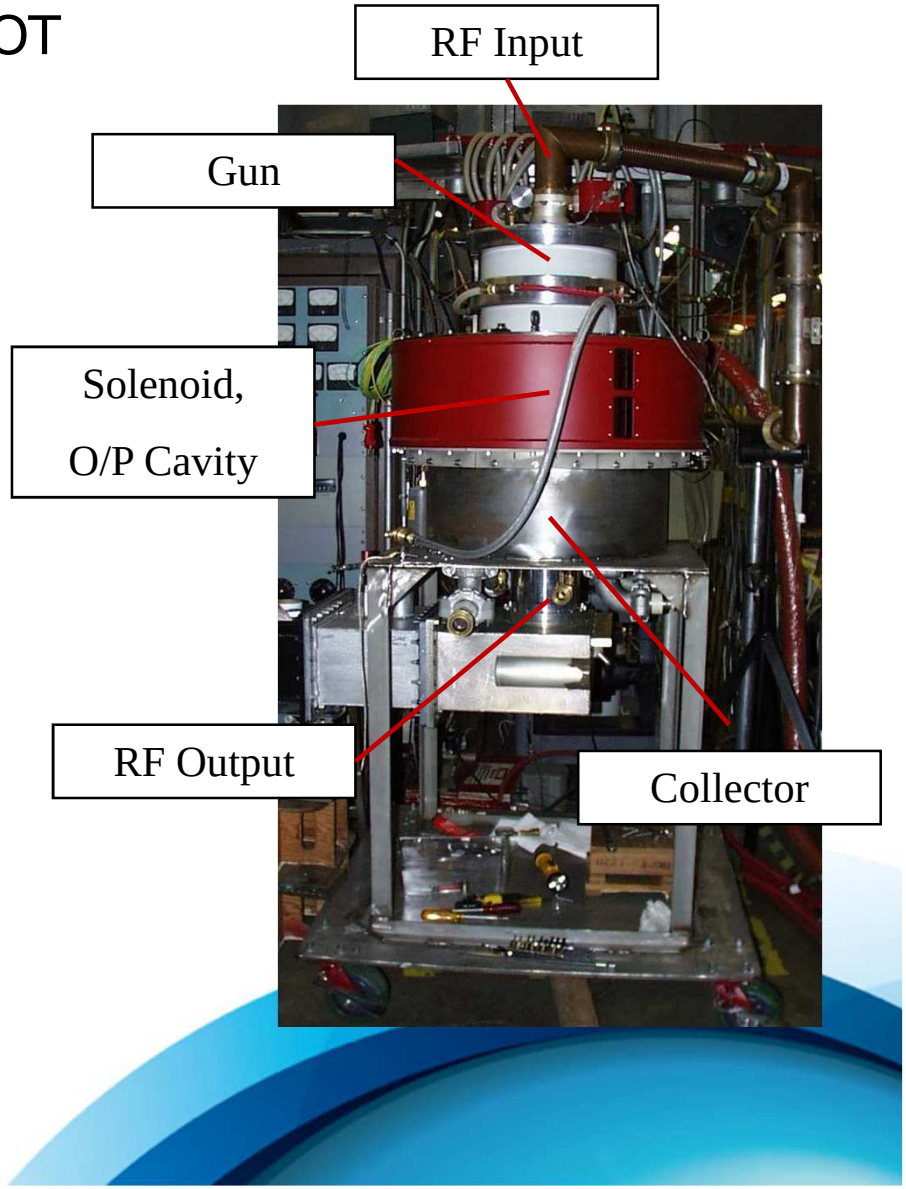
VHP-8330A IOT

Design Parameters	value	units
Power Output	1000	kW (min)
Beam Voltage	45	kV (max)
Beam Current	31	A (max)
Frequency	700	MHz
1dB Bandwidth	± 0.7	MHz (min)
Gain	23	dB (min)
Efficiency	71	% (min)
Diameter	30/76	in/cm
Height	51/130	in/cm
Weight	1000/450	lbs./kg
Collector Coolant Flow	220	gpm
Body Coolant Flow	10	gpm
O/P Window Cooling (Air)	35	cfm



Test Results (pulsed)

@ 31kV



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
- Combine ‘low power’ IOTs in a common output cavity
  - Use existing IOTs
  - Large number of IOTs for high power
- 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**

Single Beam or Multi-beam?

Single beam limits current

- High supply voltage (> 95 kV for >1 MW)

Multi-beam allows higher current

- Lower supply voltage (50 kV for > 1 MV)
  - No oil, simple protection circuits
- Higher efficiency if designed for low space charge per beam

Examples of MB Klystrons

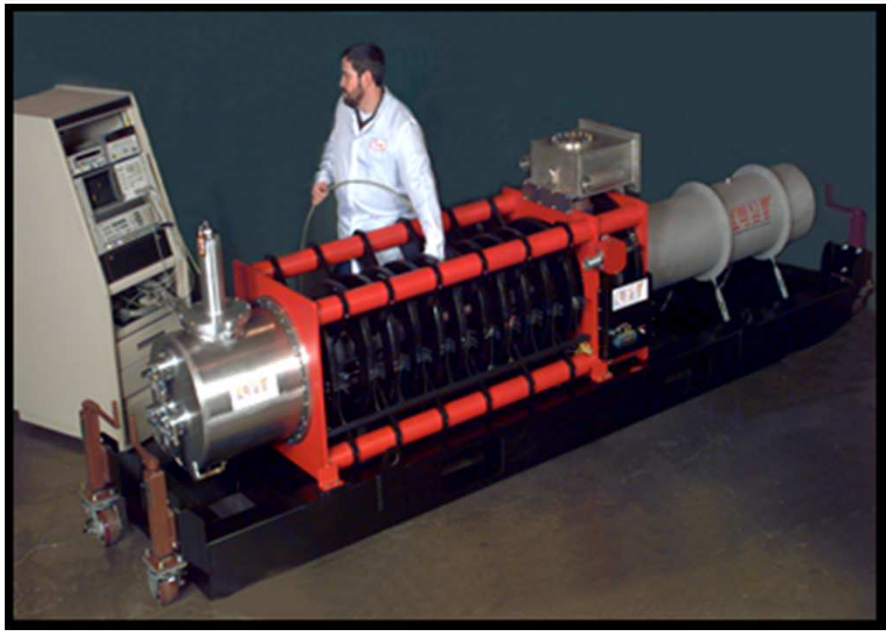
CPI – VKL-8301
10 MW 1.3 GHz

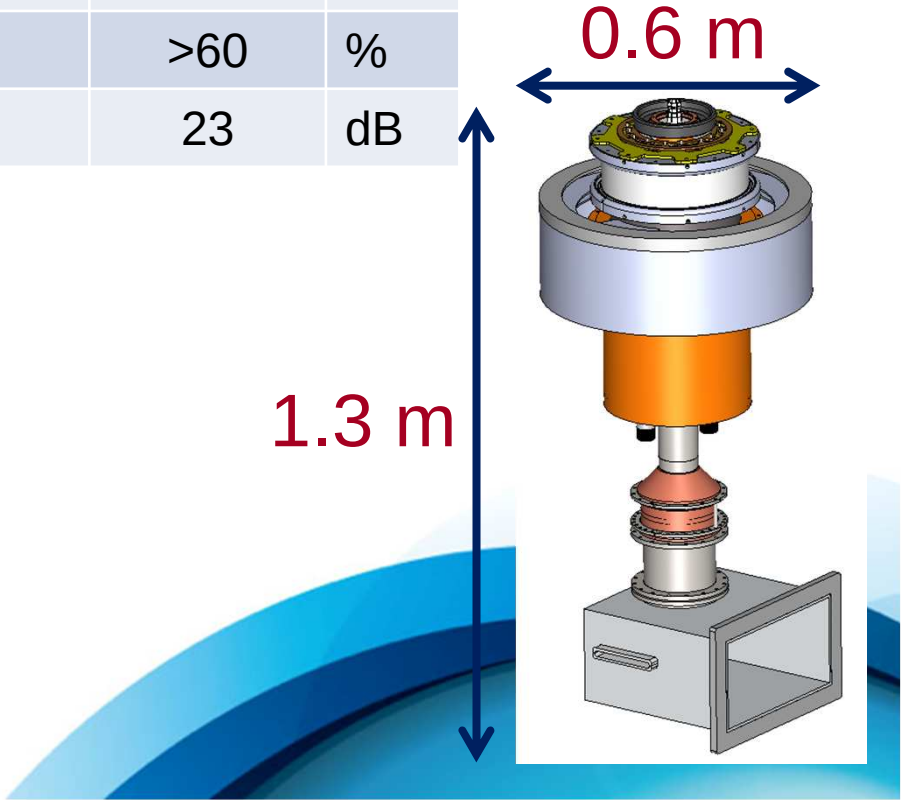
Toshiba – E3736H
10 MW 1.3 GHz

Thales – TH1802
10 MW 1.3 GHz

A 700 MHz Comparison

	Single Beam Klystron	MB IOT	
Peak output Power	1	1	MW
Cathode Voltage	95	50	kV
Beam Current	21	31	A
Efficiency at saturation	65	65 (min)	%
Est. efficiency for operation	<45	>60	%
Gain	48	23	dB

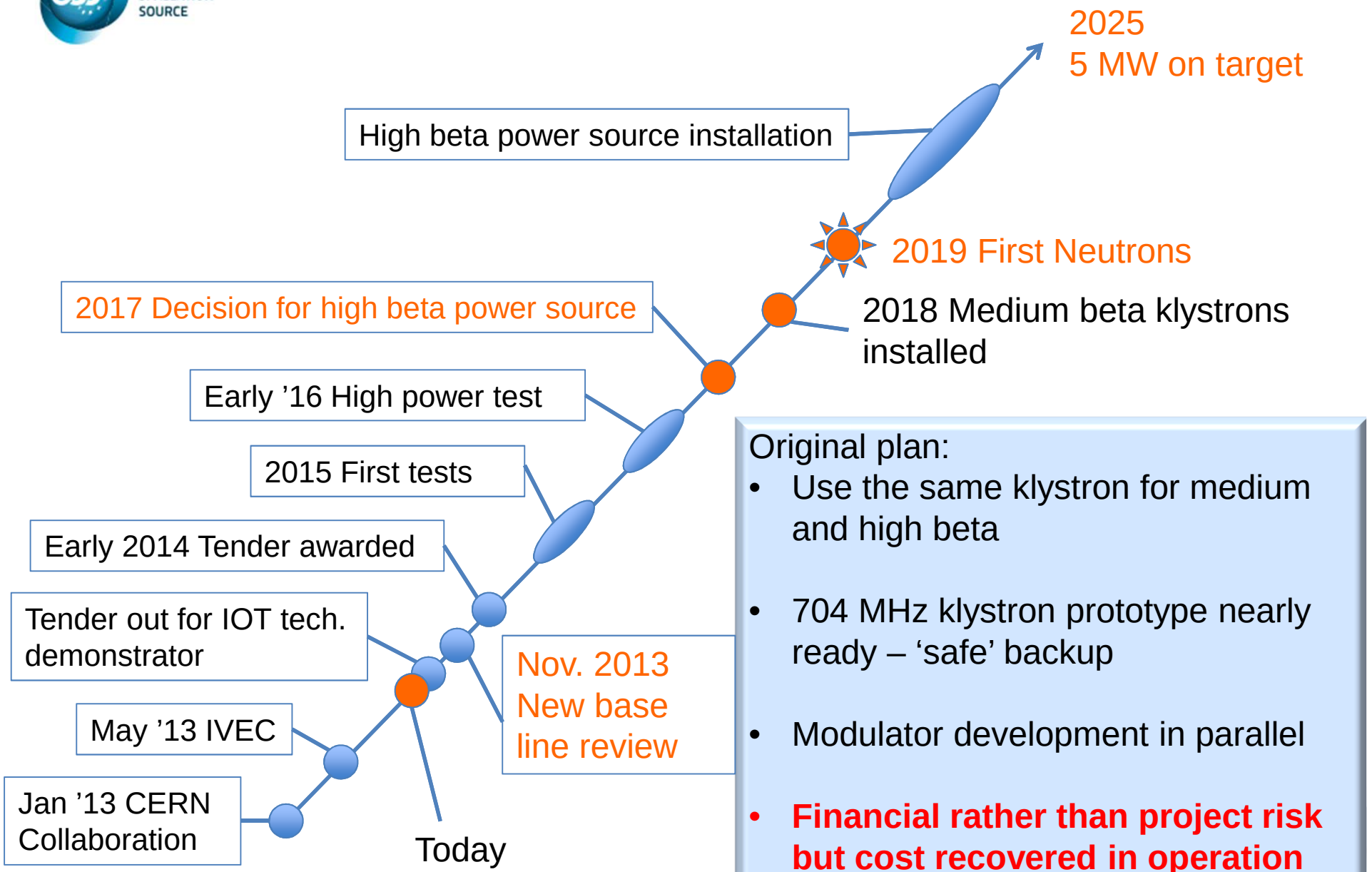




Target IOT Parameters for Prototype Build

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	2	Preference for two separate manufacturing sites
Series production	84	Plus initial 10% spares, plus ongoing supply

Schedule Considerations



Original plan:

- Use the same klystron for medium and high beta
- 704 MHz klystron prototype nearly ready – ‘safe’ backup
- Modulator development in parallel
- **Financial rather than project risk but cost recovered in operation**

Summary

- ESS will deliver an innovative Green Accelerator with high efficiency devices
- ESS RF requirement is huge
- ESS offers a Unique Opportunity to Develop and Deliver State of the Art Technology
- The IOT Development Represents No Project Risk to ESS with a Proven and Mature Technology Backup
- Cost of IOT prototype recovered in < 2 years operation on top of the initial capital cost saving on modulators

Next year we will present design and first results from IOT development

What is 5 MegaWatts?

- At 5 MegaWatts,
  - **one** beam pulse
    - has the same energy as a 16 lb (7.2kg) shot traveling at 1100 km/hour (Mach 0.93)
    - Has the same energy as a 1000 kg car traveling at 96 km/hour
    - Happens 14 x per second
  - You boil 1000 kg of ice in 83 seconds
    - A ton of tea!!!