European Spallation Source (ESS)

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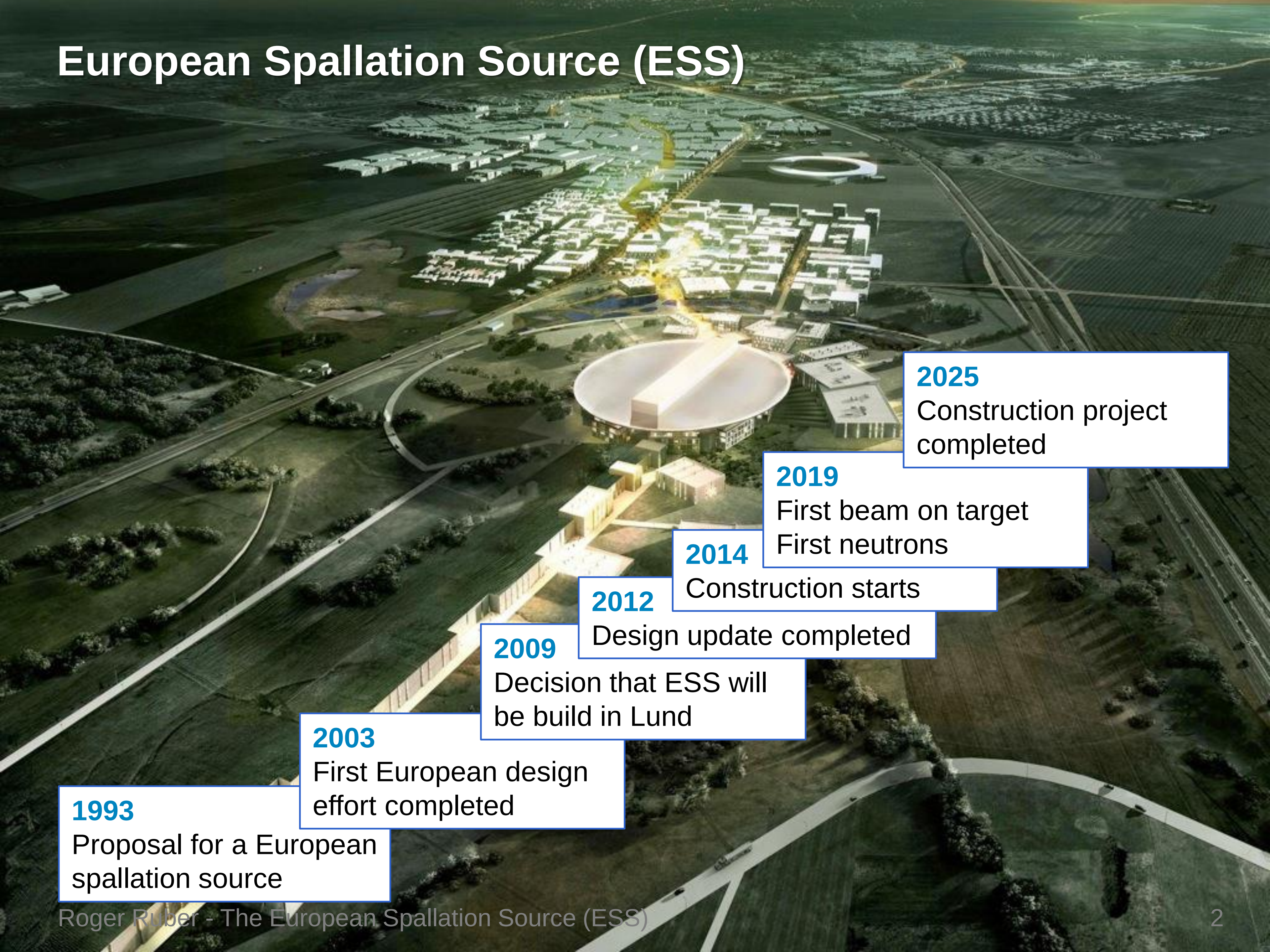
Dept. of Physics and Astronomy
Uppsala University
1 November 2016

European Spallation Source (ESS)



2025
Construction project completed

2019
First beam on target
First neutrons

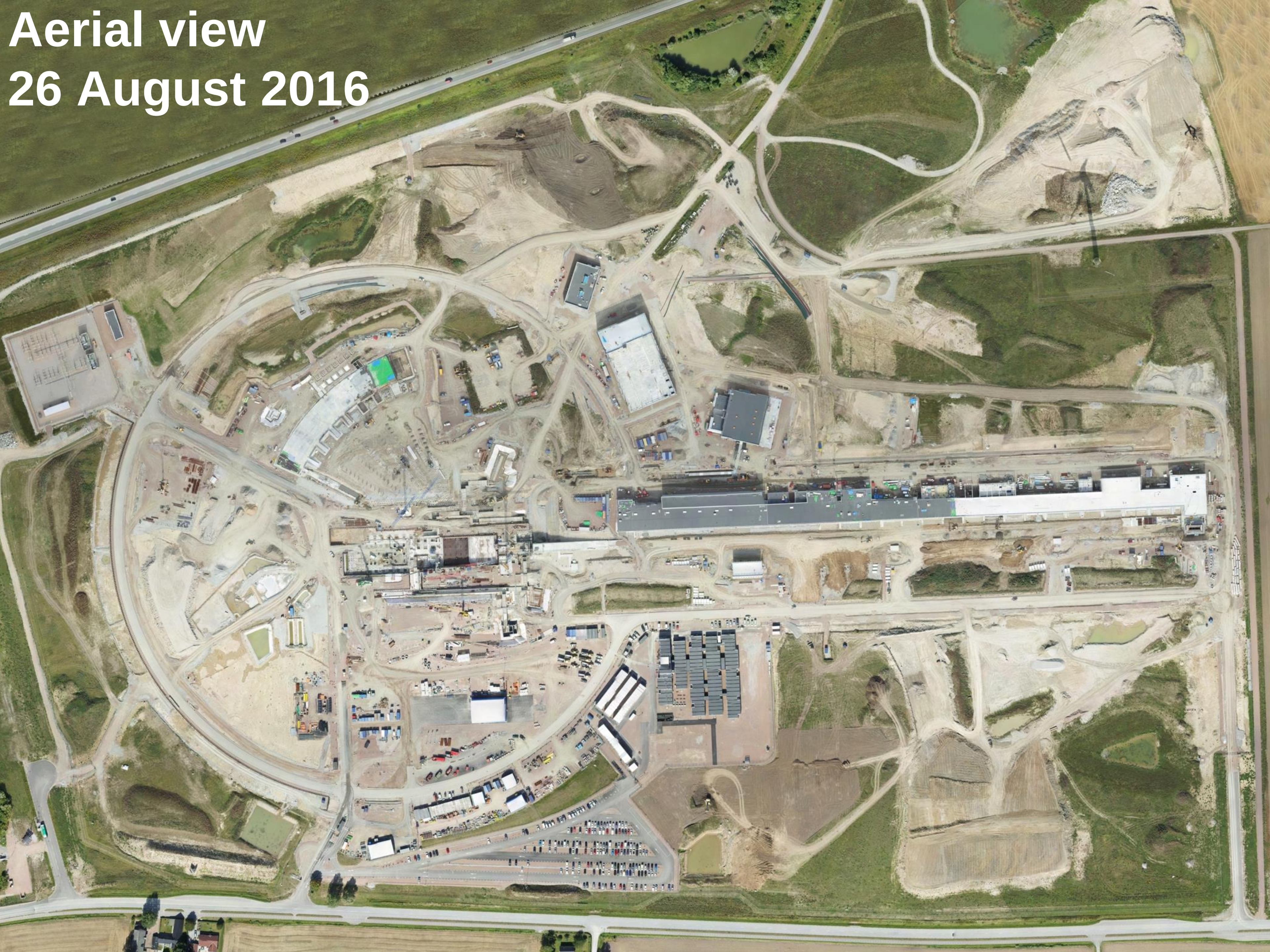
2014
Construction starts

2012
Design update completed

2009
Decision that ESS will be build in Lund

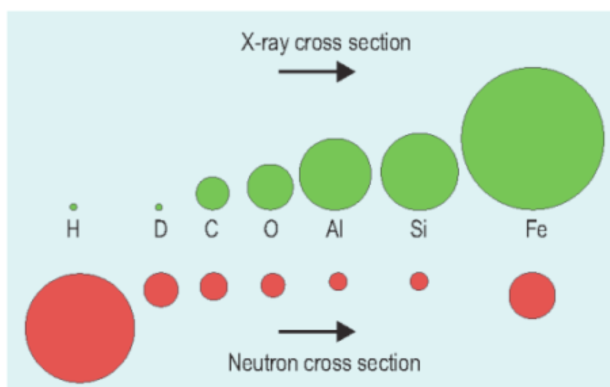
2003
First European design effort completed

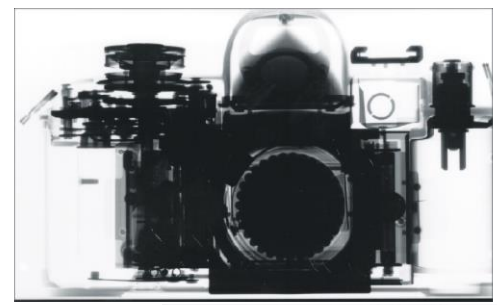
1993
Proposal for a European spallation source

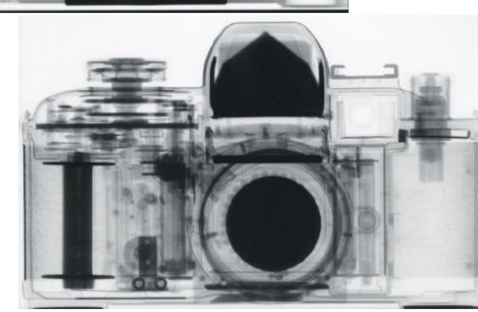

Aerial view
26 August 2016

Why Neutron Imaging?

- charge neutral:
  - deeply penetrating except for some isotopes
- nuclear interaction:
  - cross section depending on isotope (not Z), sensitive to light elements.
- spin S = 1/2:
  - probing magnetism
  - unstable $n \rightarrow p + e + \underline{\nu}_e$ with life time $\tau \sim 900s$, $I = I_0 \; e^{-t/\tau}$
- thermal energies result in non-relativistic velocities
  - mass: n ~p; E = 293 K = 25 meV, v = 2196 m/s , λ = 1.8 Å

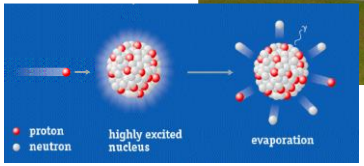




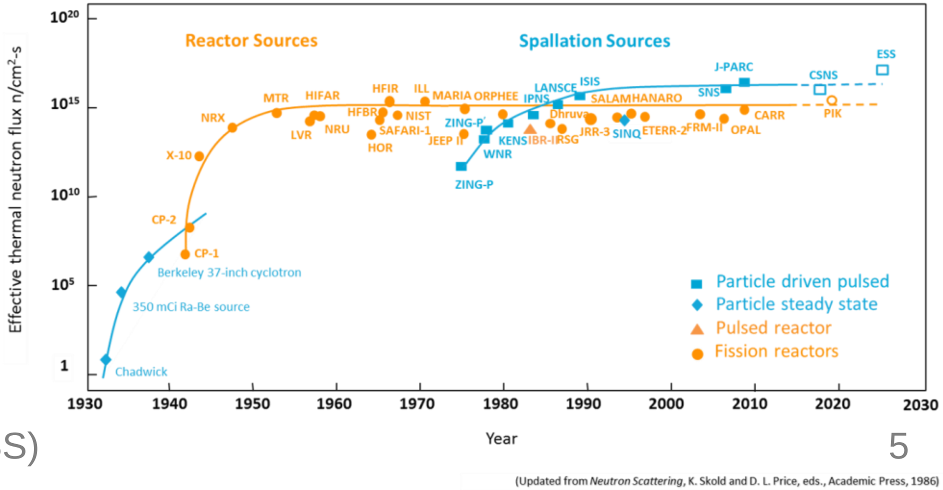


ESS Philosophy and Parameters

- User facility to replace aging research reactors
  - Lund, Sweden, next to MAX IV
    - 2019 first neutrons
    - 2019 – 2025 consolidation and operation
    - 2025 – 2040 operation
- **5 MW** pulsed **cold neutron source**, long pulse
  - **14 Hz rep. rate, 4% duty factor**
  - high availability of <u>scheduled</u> operation time (>95%)
  - short pulse (requires ring) user demand satisfied by existing facilities (ISIS, SNS, J-PARC)



- Proton beam on tungsten target
  - 2 GeV, 2.89 ms, 62.5 mA beam pulse
  - peak power 125 MW
- High intensity allows studies of
  - complex materials, weak signals, time dependent phenomena



What is 5 MW?

At 5 MegaWatt,

- one beam pulse has the same energy as
  - a 16 lb (7.2kg) shot traveling at 1100 km/h (Mach 0.93)
  - a 1000 kg car traveling at 96 km/hour
- with 14 beam pulses per second
  - you boil 1000 kg of ice in 83 seconds
    - A ton of tea!!!

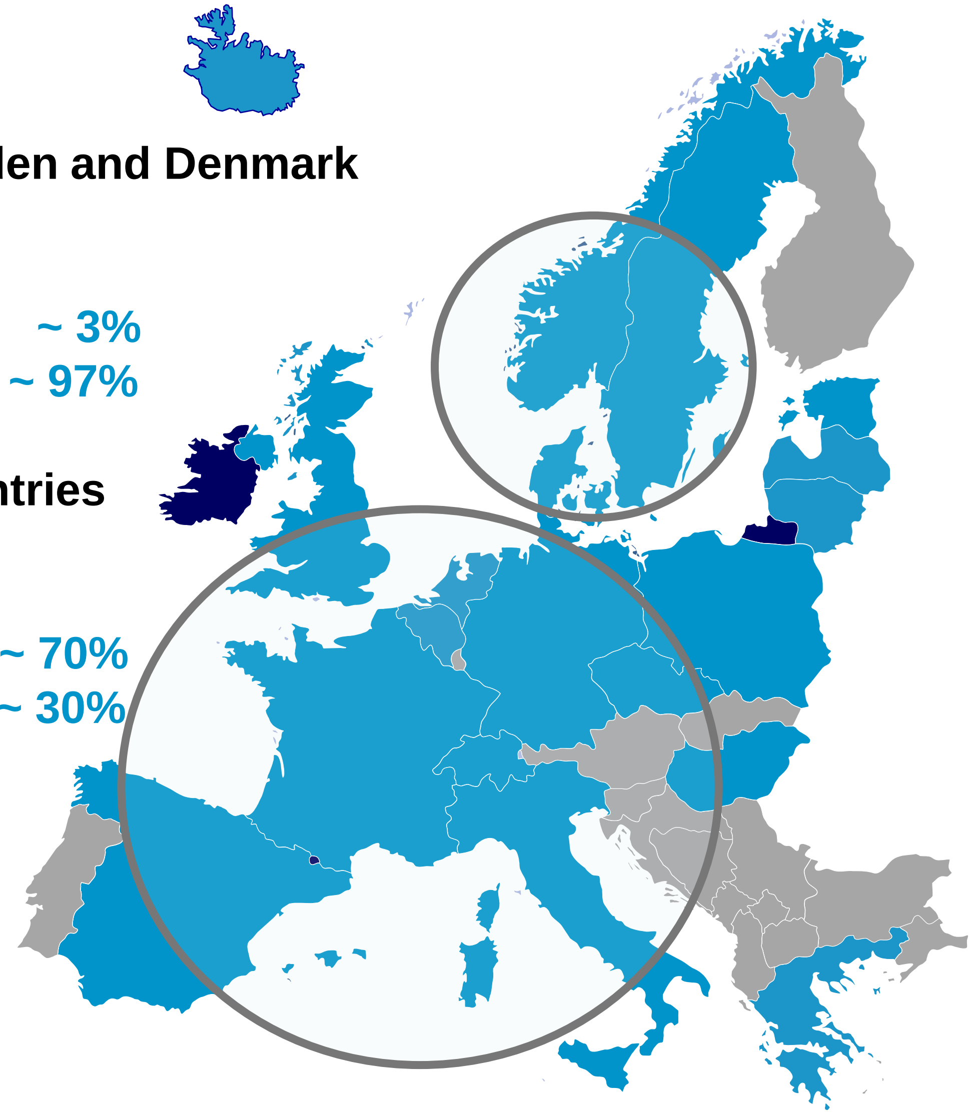
The Organization

Host Countries of Sweden and Denmark

- **47,5% Construction**
- **15% Operations**
- **In-kind Deliverables ~ 3%**
- **Cash Investment ~ 97%**

Non Host Member Countries

- **52,5% Construction**
- **85% Operations**
- **In-kind Deliverables ~ 70%**
- **Cash Investment ~ 30%**



How it Works

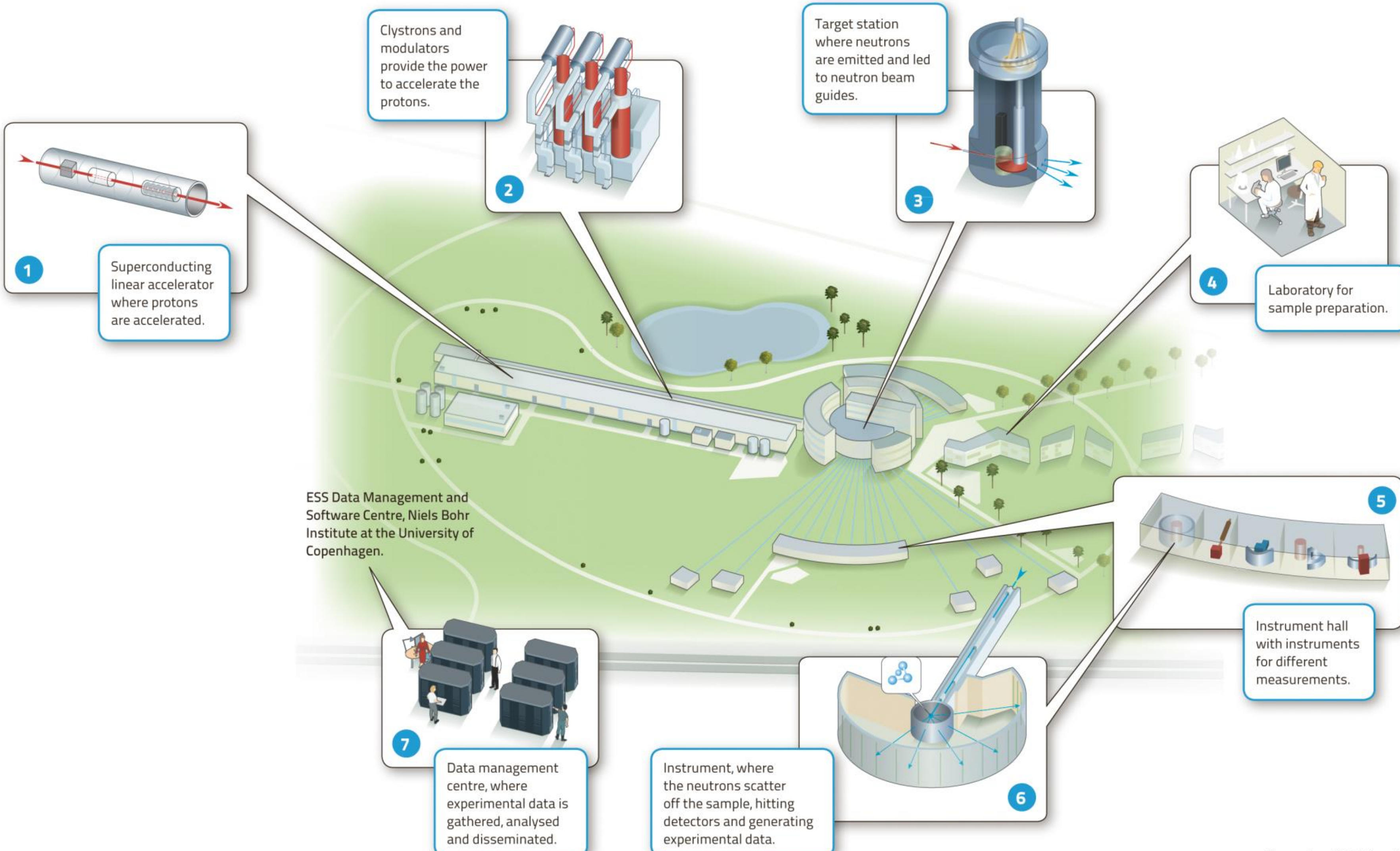
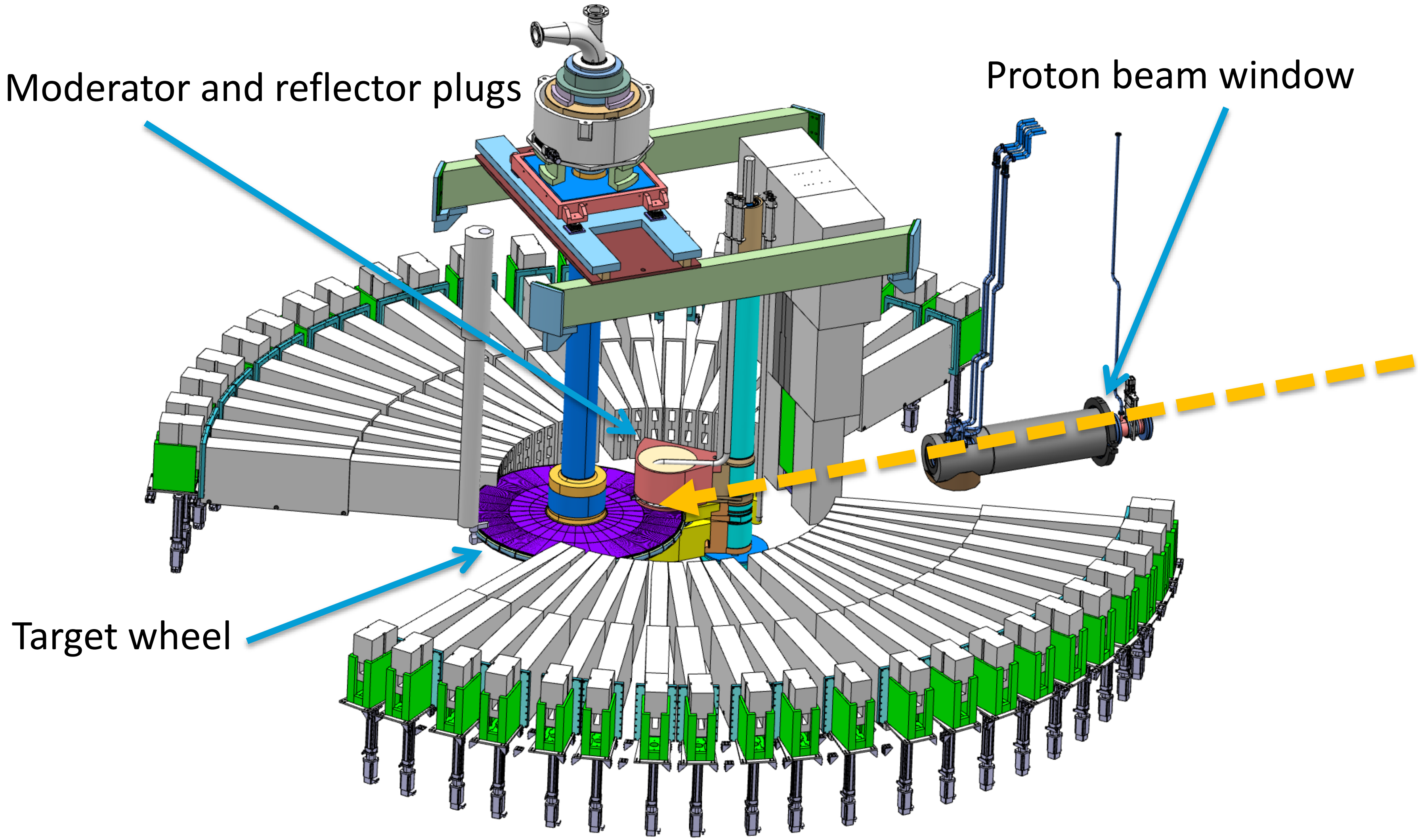


Illustration: ESS, Lönegård

The ESS Target



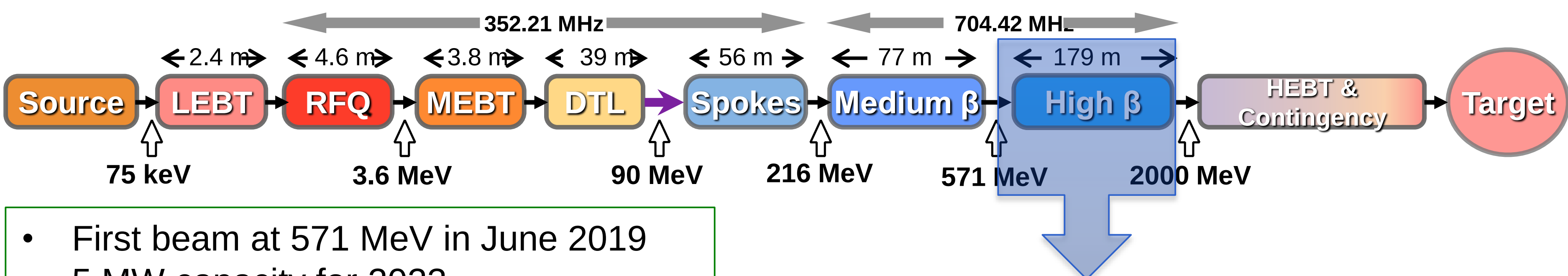
The ESS Accelerator

Design Drivers:

- High Average Beam Power
  - 5 MW
- High Peak Beam Power
  - 125 MW
- High Availability

Key parameters:

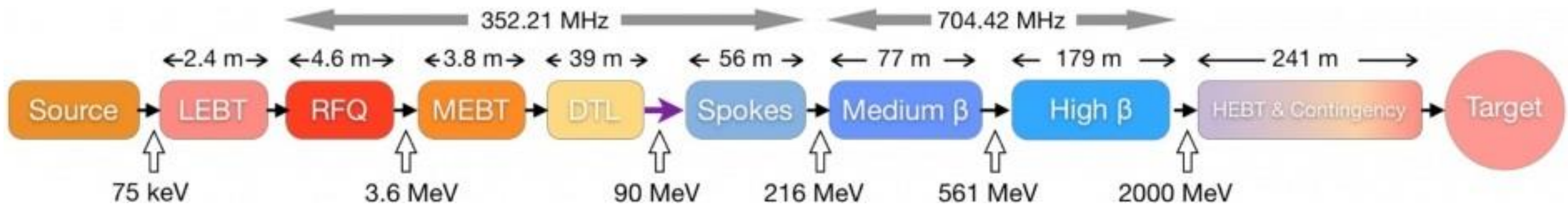
- 2.86 ms pulses
- 2 GeV
- 62.5 mA peak
- 14 Hz
- Protons (H+)
- Low losses
- Minimize energy use
- Flexible design for mitigation and future upgrades



- First beam at 571 MeV in June 2019
- 5 MW capacity for 2023

RF sources for HB part is the scope contingency for accelerator

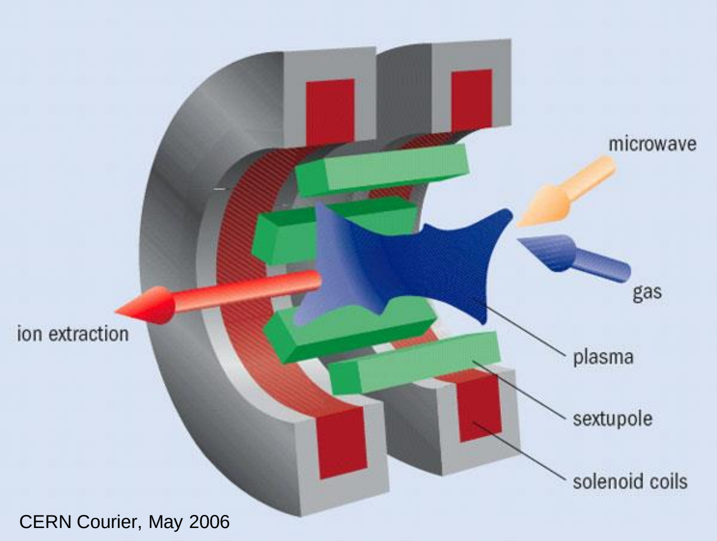
The ESS Accelerator



	Length [m]	No. Cavities	β	No. Magnets	No. Steerers	No. Sections	Power [kW]
LEBT	2.38			2 Solenoid	2 x 2	1	
RFQ	4.6	1				1	1600
MEBT	3.83	3		11 Quad	10 x 2	1	15
DTL	38.9	5		PM-Quads	15 x 2	5	2200
LEBT + Spoke	55.9	26	0.50	26 Quad	26	13	330
Medium Beta	76.7	36	0.67	18 Quad	18	9	870
High Beta	178.9	84	0.86	42 Quad	42	21	1100
HEBT	130.4		(0.86)	32 Quad	32	15	
DogLeg	66.2			12 Quad + 2D	14		
A2T	46.4			6 Quad + 8 Raster			
	604.21	**155**					

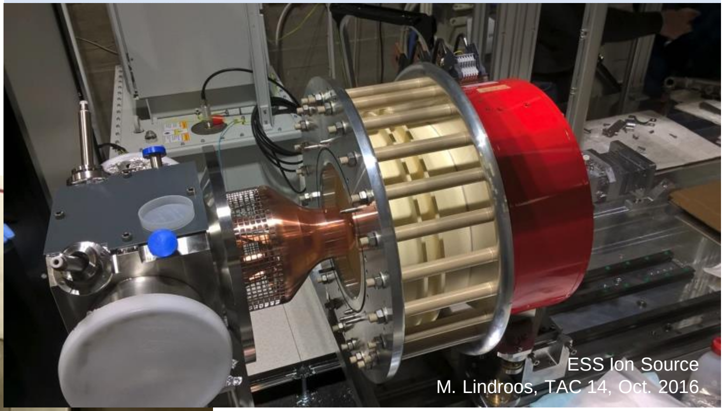
Ion Source

Parameters	Value
Nominal proton peak current	74 mA
Proton fraction	> 80 %
Stable operation current range	60-74 mA
Current stability(over 50us period)	± 2 %
Pulse to pulse variation	± 3.5 %
Beam Energy	75 keV (±0.01)
Distance between pulses	1 Hz< f <14 Hz
Restart after vacuum break Restart after cold start	<32 h <16 h



CERN Courier, May 2006

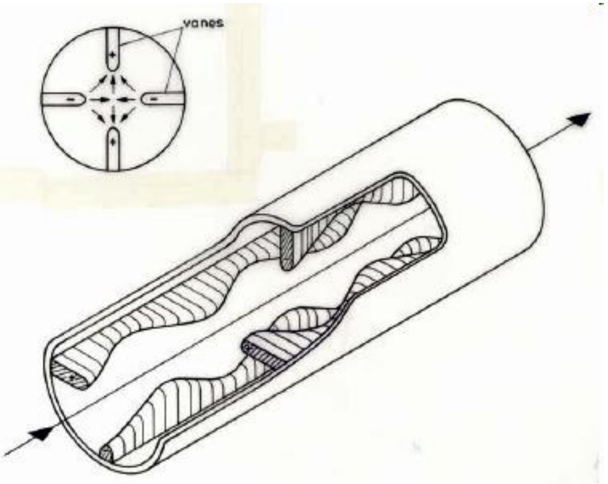
Parameters	Value
Beam current change (2 mA step, ±1 mA res.)	2-74 mA
Nominal pulse length	2.86 ms
Pulse length range (±0.001 ms)	0.005-2.88 ms
99 % rms norm. emit. at RFQ input	< 2.25 pi.mm.mrad
Twiss parameter: α	α= 1.02 ±20%
Twiss parameter: β	β= 0.11 ±10%
Rise and fall time	<20 us
Maximum LEBT pressure	6e-5 mbar

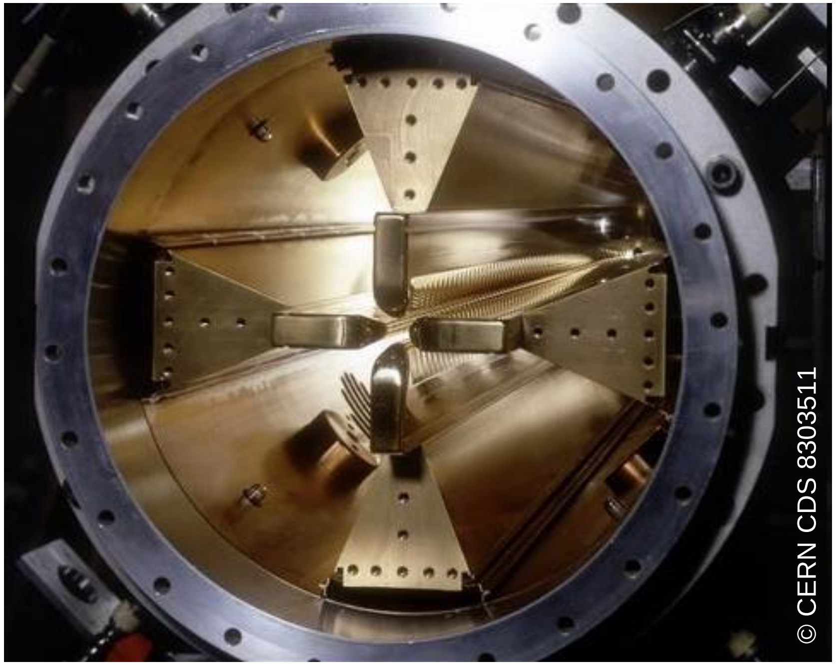

ESS Ion Source
M. Lindroos, TAC 14, Oct. 2016


First Plasma from the ESS Ion Source
M. Lindroos, TAC 14, Oct. 2016

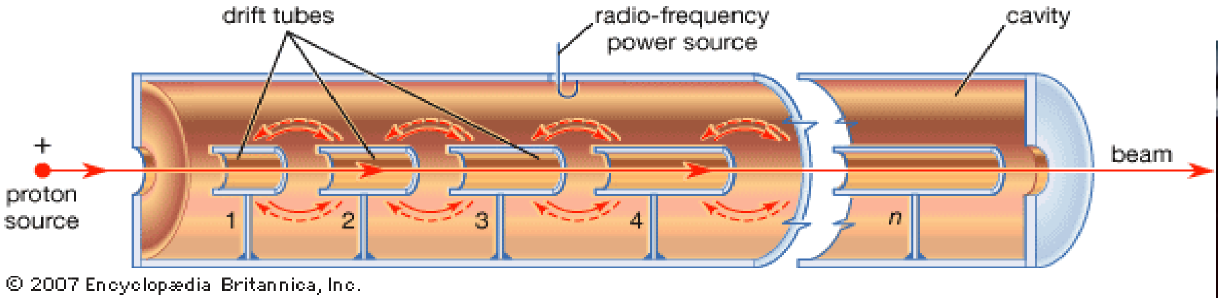
RF Quadrupole (RFQ)

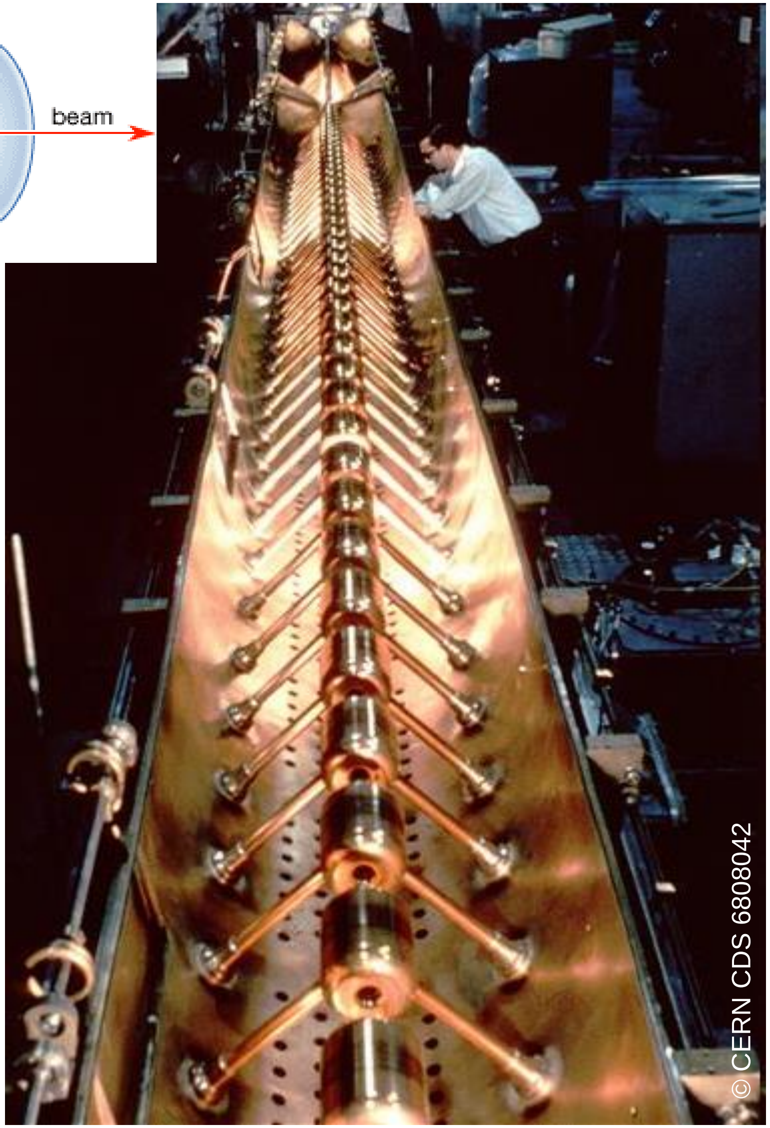
- electric quadrupole mode
  high field quality
- RF electric field concentrated near the vane tips, hence
  strong transverse focusing
- acceleration through
  longitudinal modulation
  pattern, hence
  effective array of
  accelerating cells





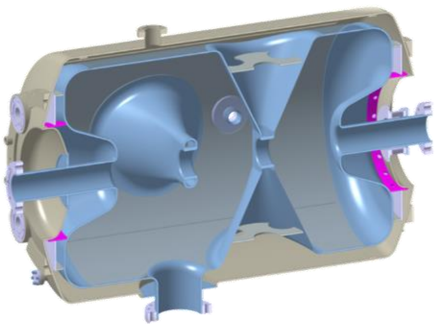
Drift Tube Linac (DTL)

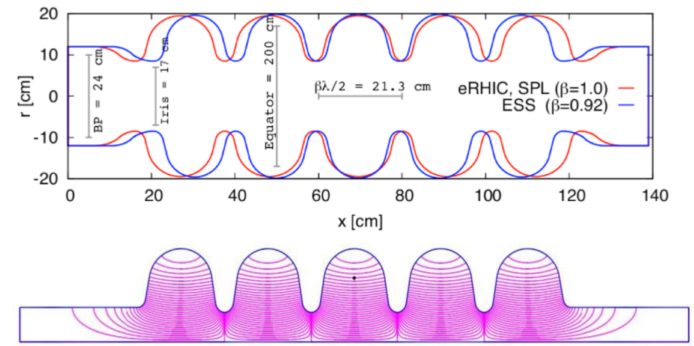


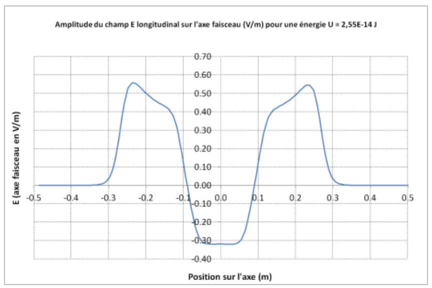


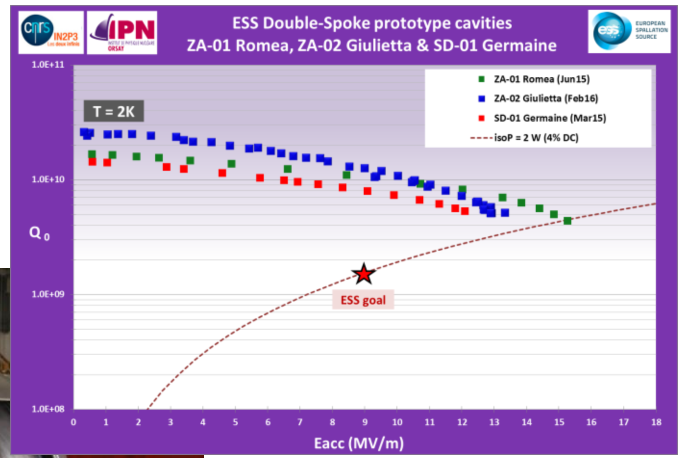
- drift tube shields particle while field direction is reversed
- drift tube length adapted to particle velocity
- permanent magnet included for focusing

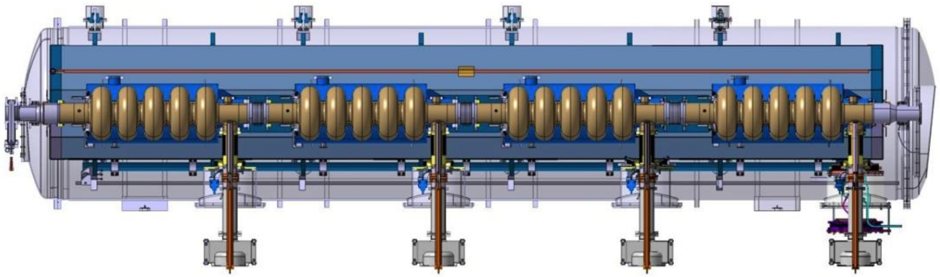
Superconducting Cavities (SRF)





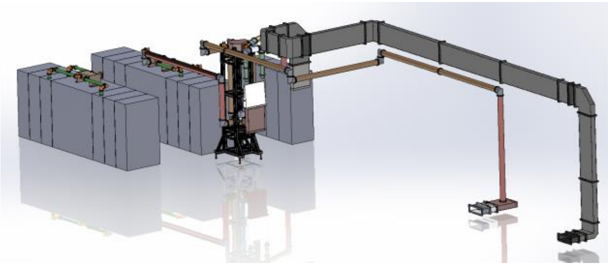




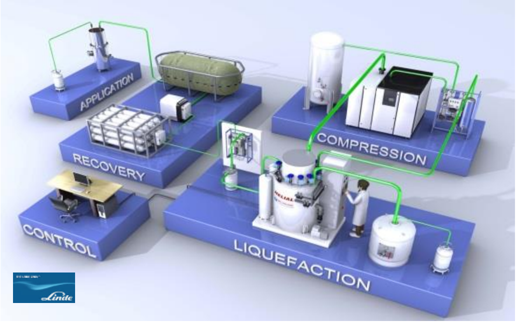


Horizontal SRF Test Stand

Three main subsystems:



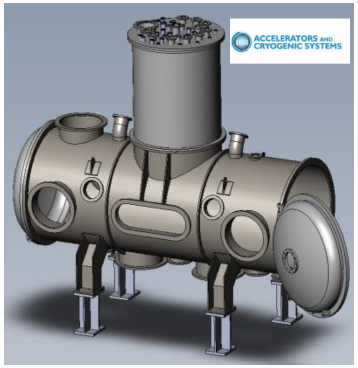
RF Power Source



Cryogenics

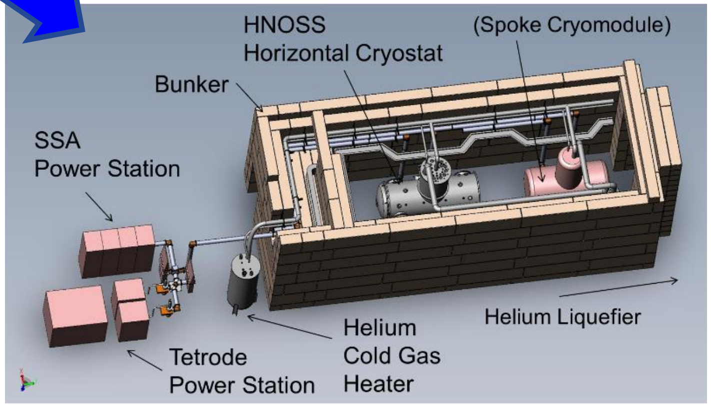
Courtesy of P. Duthil

SRF Cavity
(superconducting)



Cryostat

Implementation



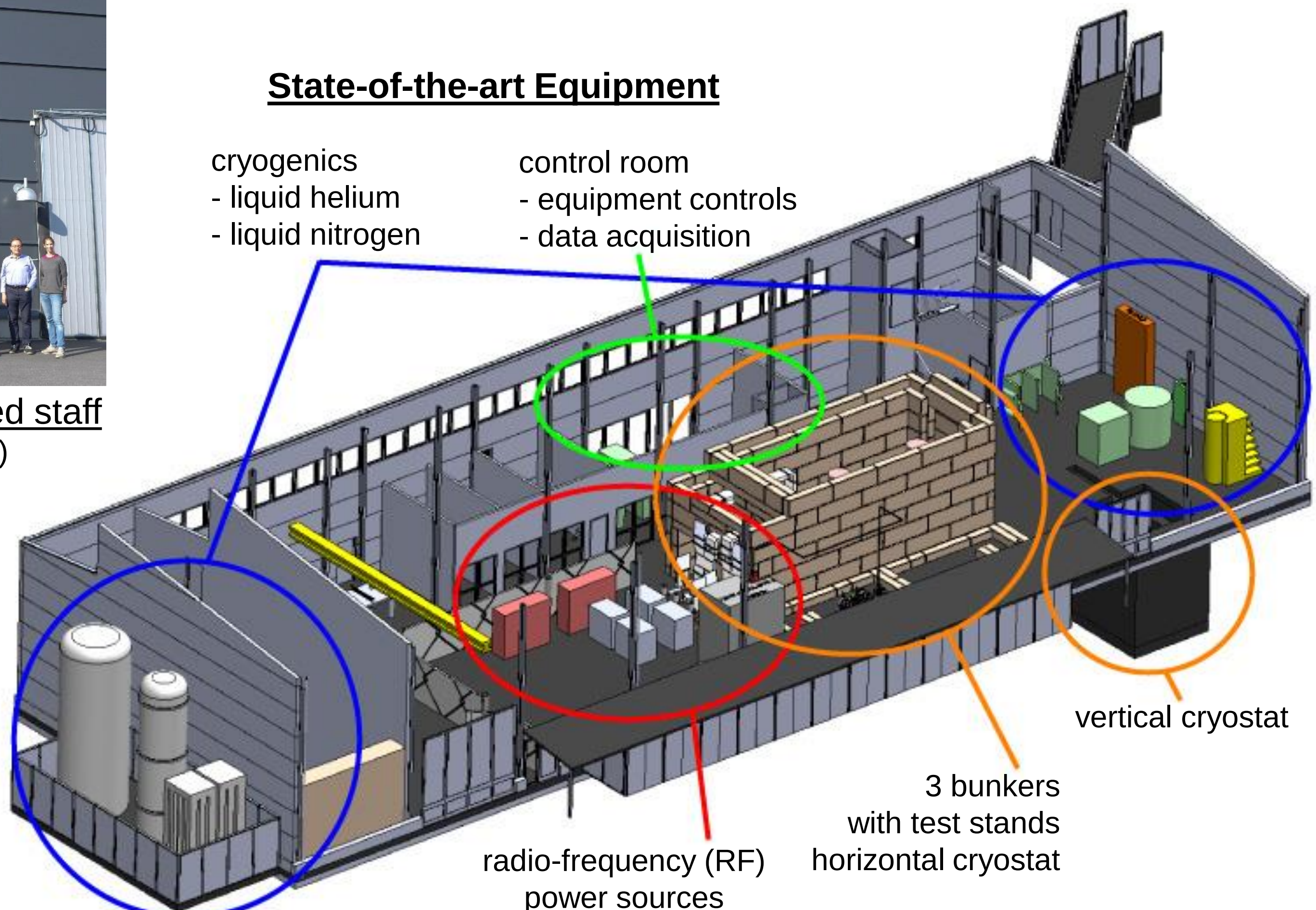
FREIA Laboratory: Test Facility in Uppsala

Facility for Research Instrumentation and Accelerator Development

<u>Competent and motivated staff</u>
collaboration of physics (IFA)
and engineering (Teknikum).

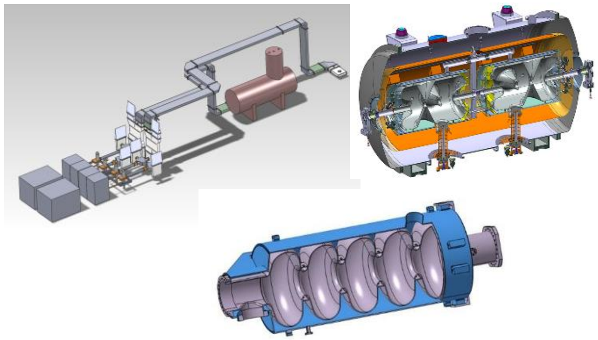
Funded by KAWS, Government, Uppsala Univ.

<u>State-of-the-art Equipment</u>



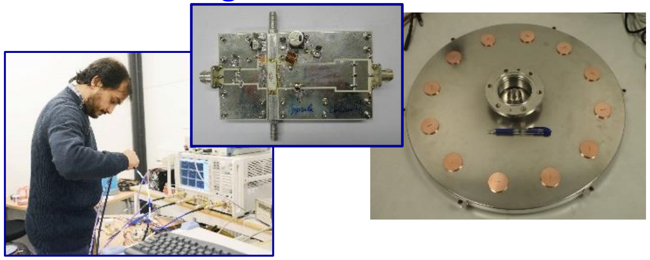
FREIA Laboratory Overview of Activities

ESS SRF Linac



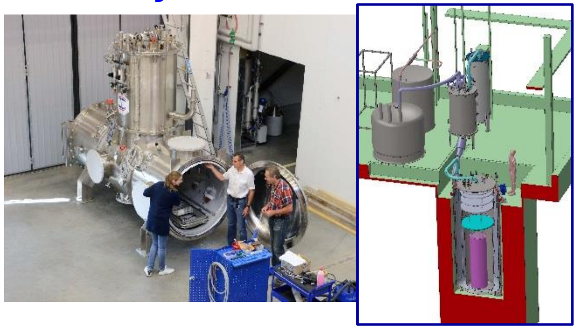
Cryo Distribution

High Power RF

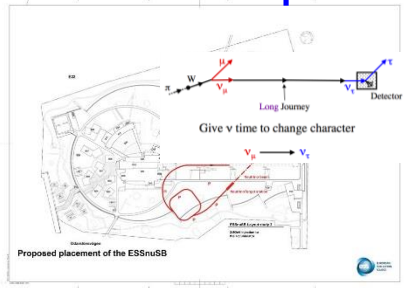


CLIC / CTF3

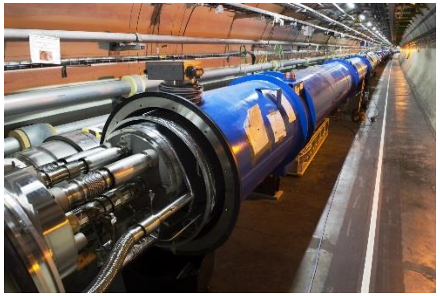
Cryo Test Stands



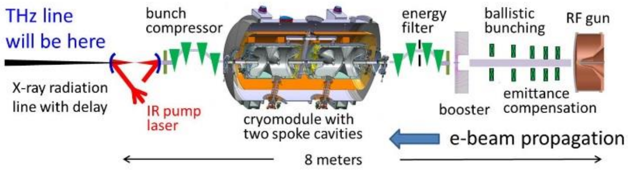
ESS Neutrino Super-beam



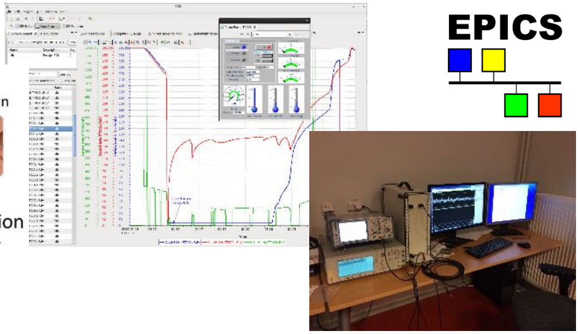
HiLumi LHC



THz Coherent Light Source



Controls & Data Acquisition



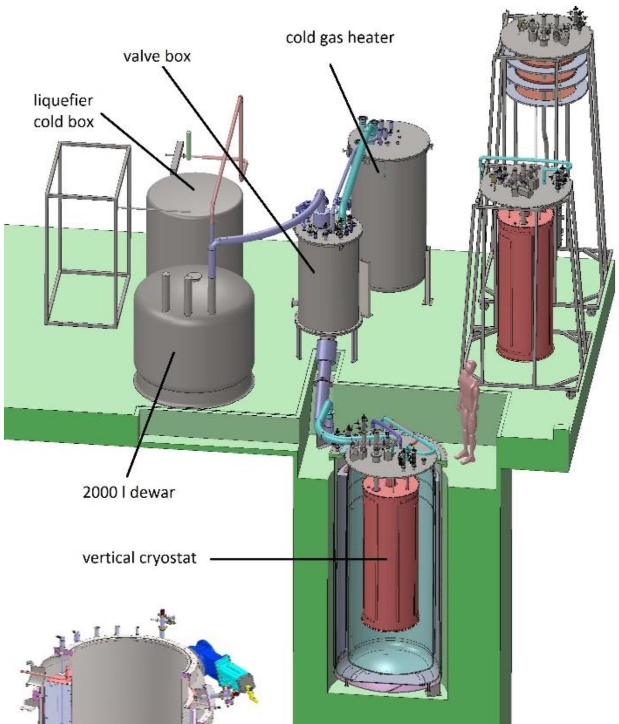
EPICS

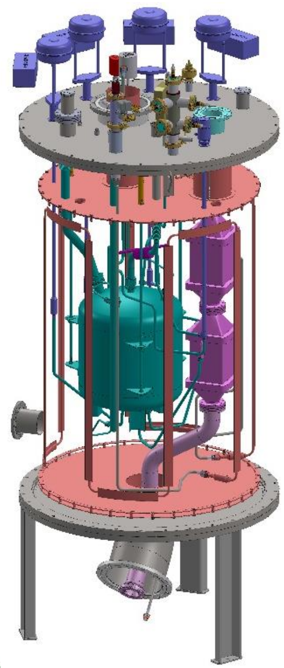
HNOSS Horizontal Cryostat

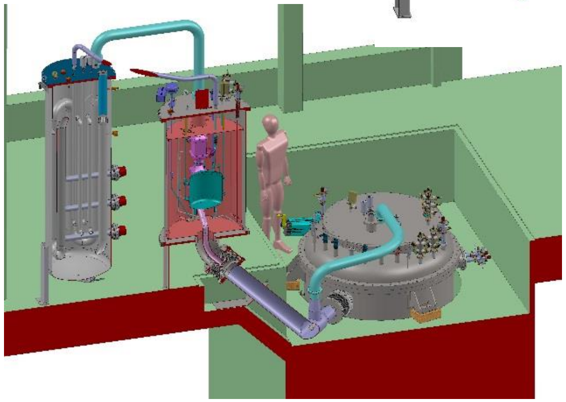
HNOSS: Horizontal Nugget for Operation of Superconducting Systems

- Main Vacuum Vessel
  - 3240 x ø1200mm inner volume
  - “beam” axis at 1600mm
- Valve box (on top of main vessel)
  - distribute cryogens
  - 4K and 2K pots, JT-valve, heat exchanger
  - 5K supercritical helium
- LN2 and LHe transfer lines
  - interconnection box to distribute cryogens to HNOSS and CM
- Cold gas re-heater
- Control system

Gersemi Vertical Cryostat







Under construction

- Operation modes
  - vacuum
  - sub-atmospheric liquid bath
  - pressurized liquid bath
- Main Vacuum Vessel
  - 4436 x ø1100mm inner volume
  - 2869 mm below lambda plate
- Valve box
  - distribute cryogens
  - 4K pot, JT-valve, heat exchanger
  - 5K supercritical helium
- LN2 and LHe transfer lines
- Cold gas re-heater
- Control system

High Power RF Amplifiers

352 MHz, 400 kW, 3.5 ms, 14-28 Hz

- Uppsala design
- tetrode tube TH595
- prototype for ESS SRF spoke linac
- industrial manufacturing
  - Itelco-Electrosys (Orvieto, IT)
  - DB Elettronica (Padua, IT)

352 & 400 MHz, 50 kW, CW

- CERN (loan since Feb.2015)
- tetrode tube TH571b

Controls

Controls and interlock systems

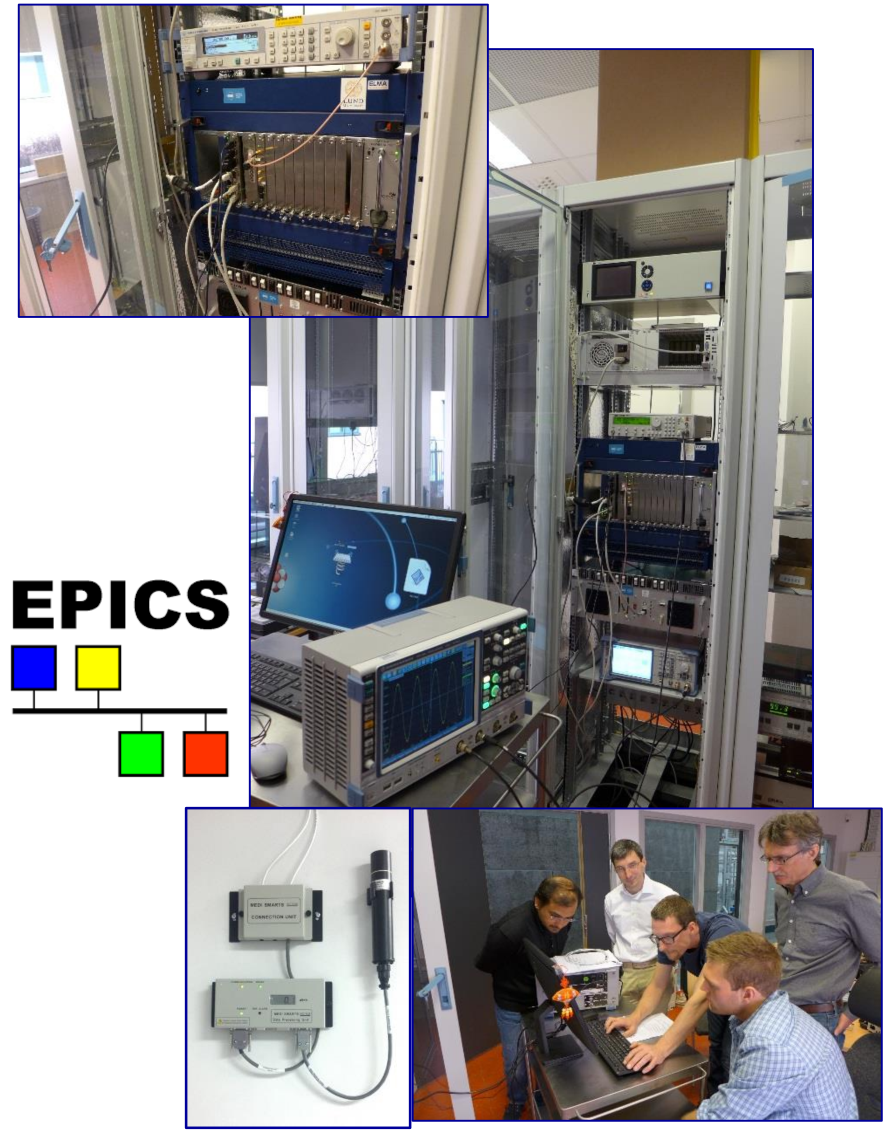
- EPICS interface, data archiver
- connecting different sub-systems
  - Linde, Cryo Diffusion, Leybold
- different hardware
  - Siemens PLC, Nat.Instr. cRIO

Radiation monitoring system

- Rotem MediSmart
- 2 inside, 3 outside bunker

In-house development LLRF

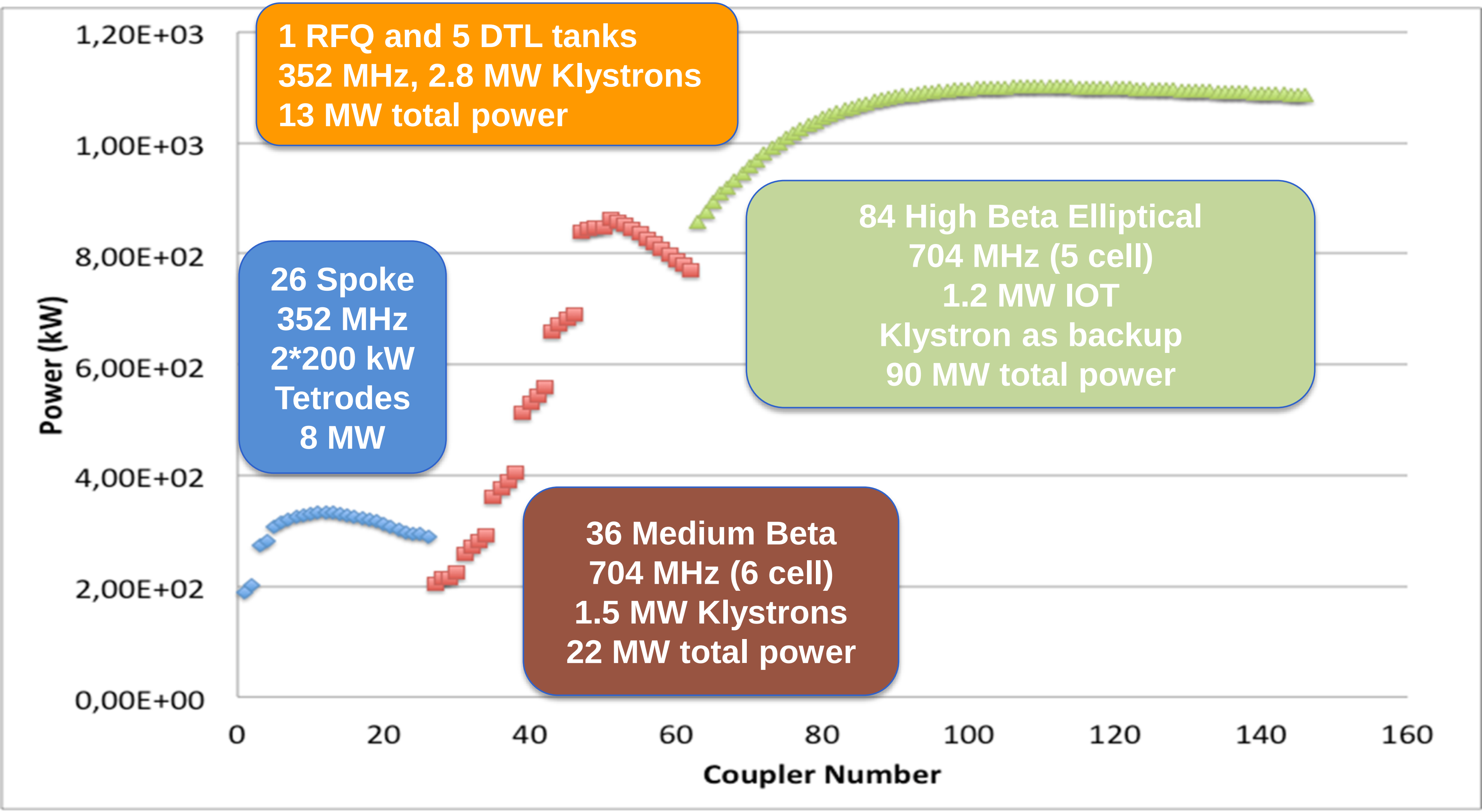
- Nat. Instr. PXI and LabVIEW
- self-excited loop with digital phase control
- extended RF measurements



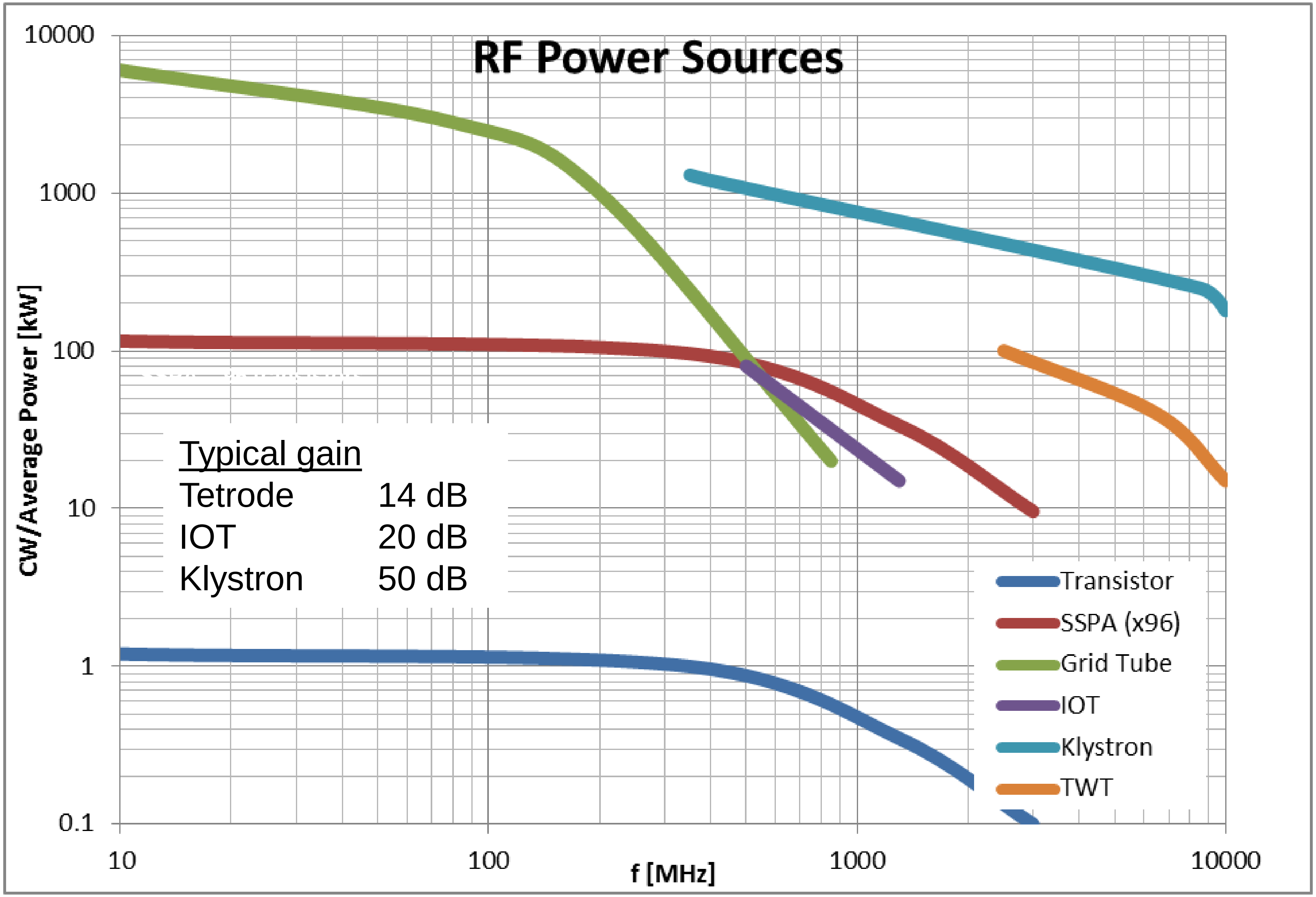
High Power
Radio Frequency
Amplifiers

RF Power Profile

155 cavities, 133 MW peak power (4% duty factor), 5 MW average



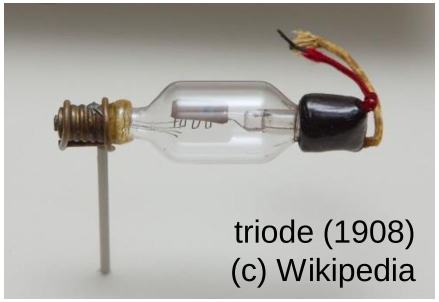
Overview Power Sources

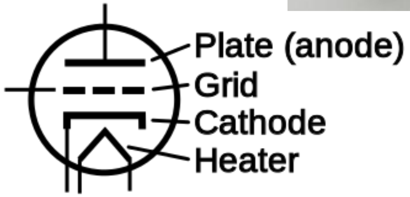


Courtesy Erk Jensen (CERN)

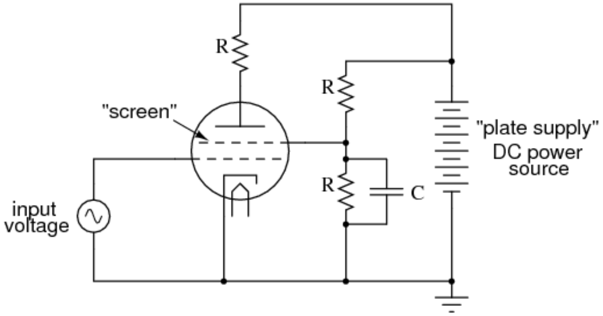
Grid Tube Microwave Amplifiers

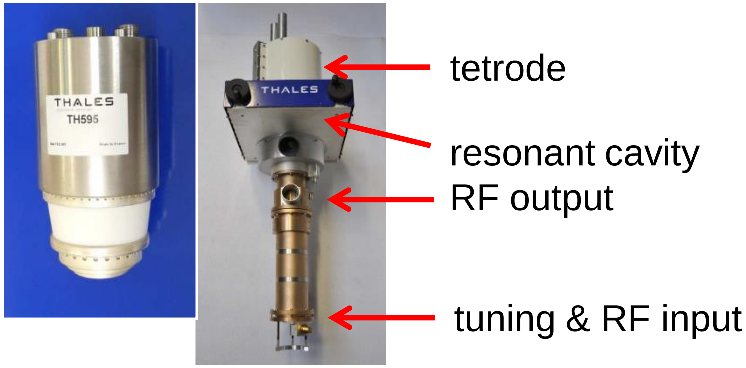
- Diode
  - first vacuum tube (1904)
  - used as radio receiver detector
- Triode
  - three electrodes, "gridded" tube (1908)
- Tetrode
  - four electrodes (1920) adds the screen grid
    - shields the control grid from the anode
    - decreases signal feedback at high frequency
  - disadvantage: secondary emission
    - from cathode, absorbed by screen grid
    - decreases current, hence amplification
  - **uses external resonant cavity**


triode (1908)
(c) Wikipedia



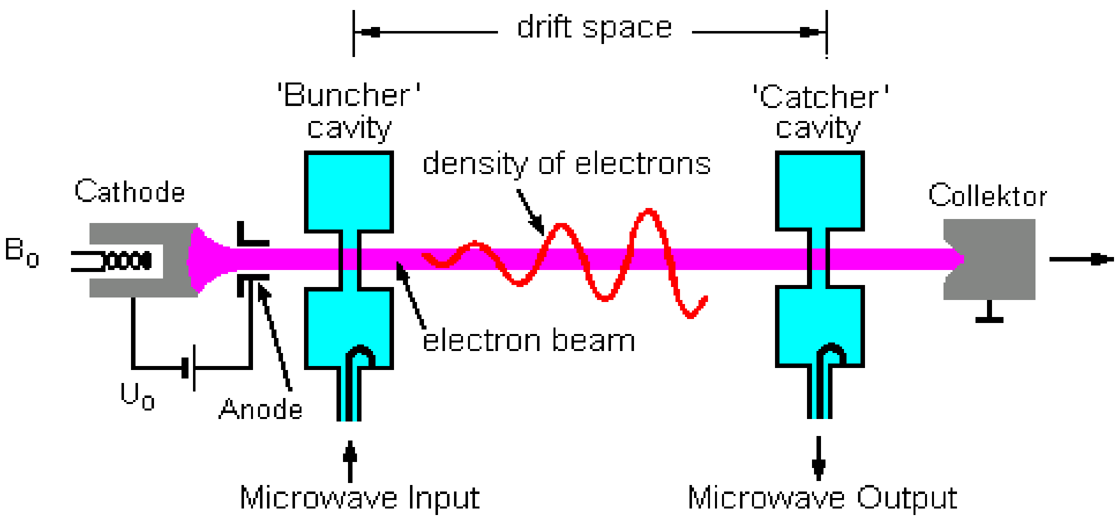
Tetrode amplifier circuit (c) AllAboutCircuits.com

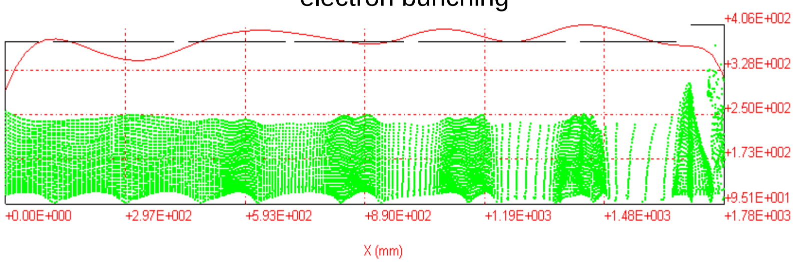


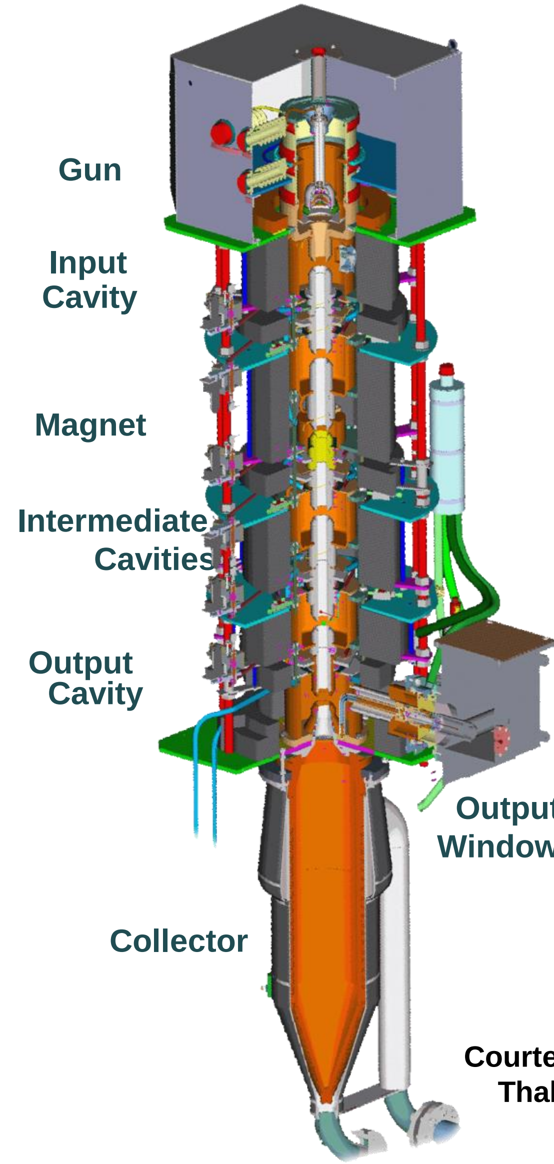


Klystron Microwave Amplifier

- vacuum tube amplifier by electron density bunching
- 200 MHz – 20 GHz
- <1.5 MW ave.; <150 MW peak

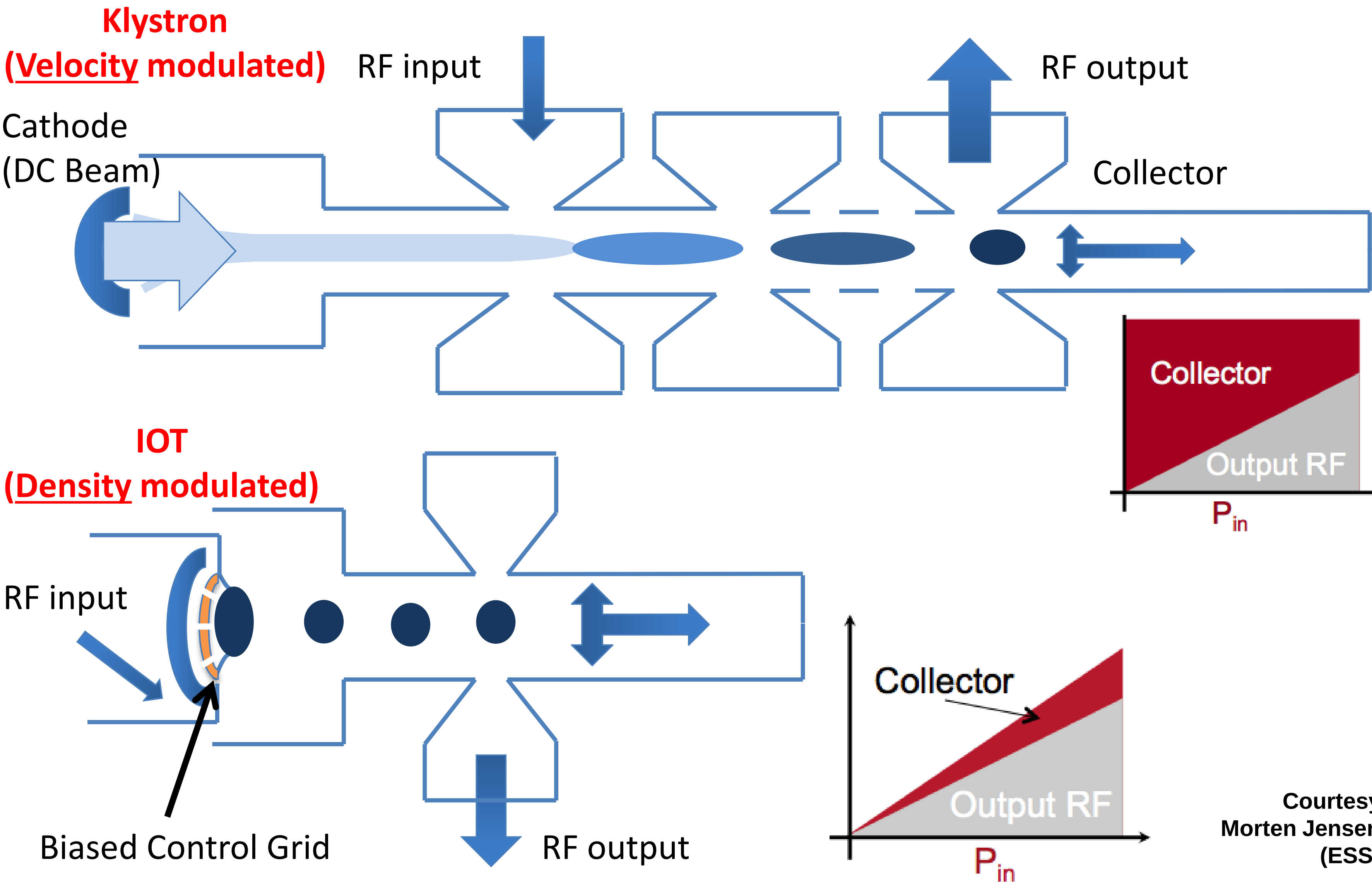






Courtesy Thales

Main Principles of Klystron and IOT

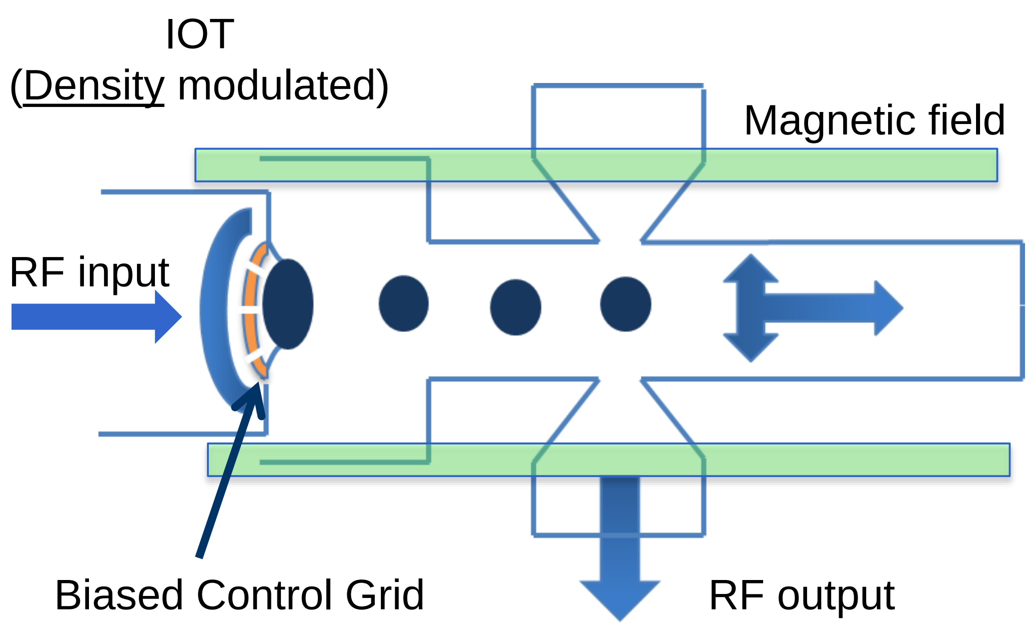


Courtesy
Morten Jensen
(ESS)

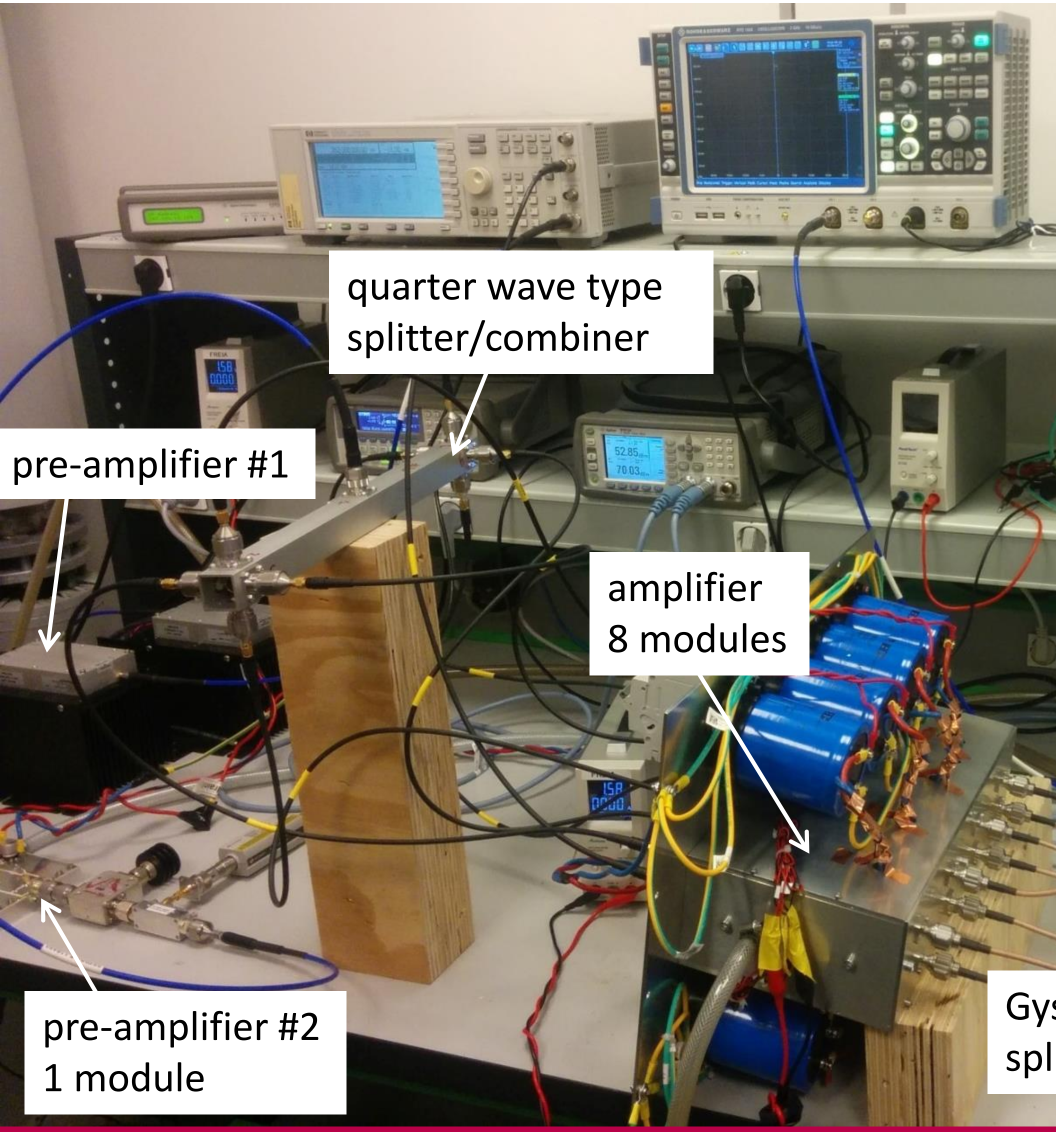
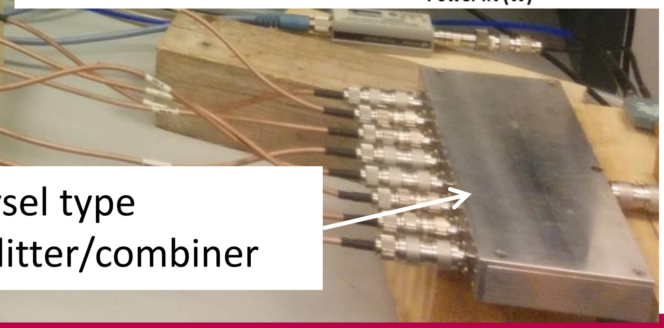
Inductive Output Tube

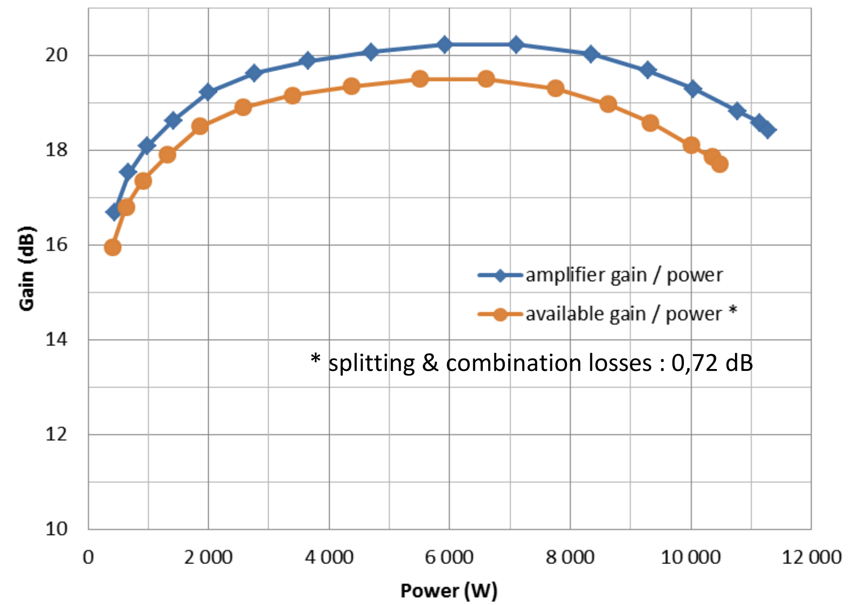
- IOT is a cross over between klystron and gridded tube
  - Reduced velocity spread compared to klystrons
  - Higher efficiency
  - Lower gain
  - No pulsed high voltage (but still pulsed current)

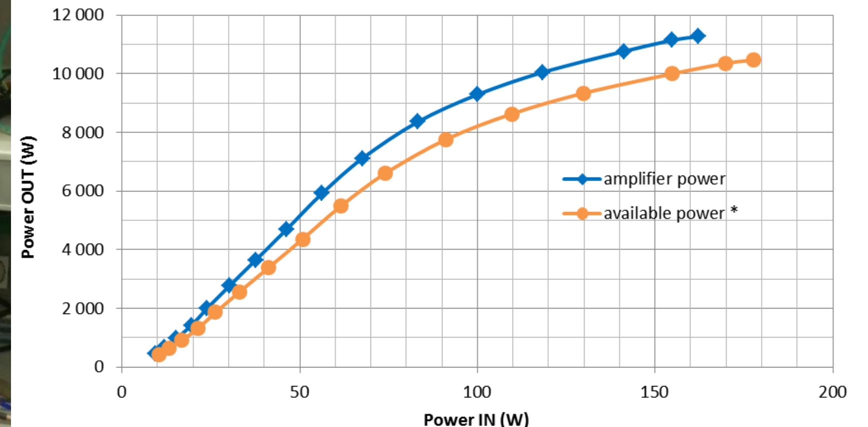
- Typical gain factor
  - tetrode: 14 dB
  - IOT: 20 dB
  - Klystron: 50 dB



10 kW 352 MHz amplifier at FREIA





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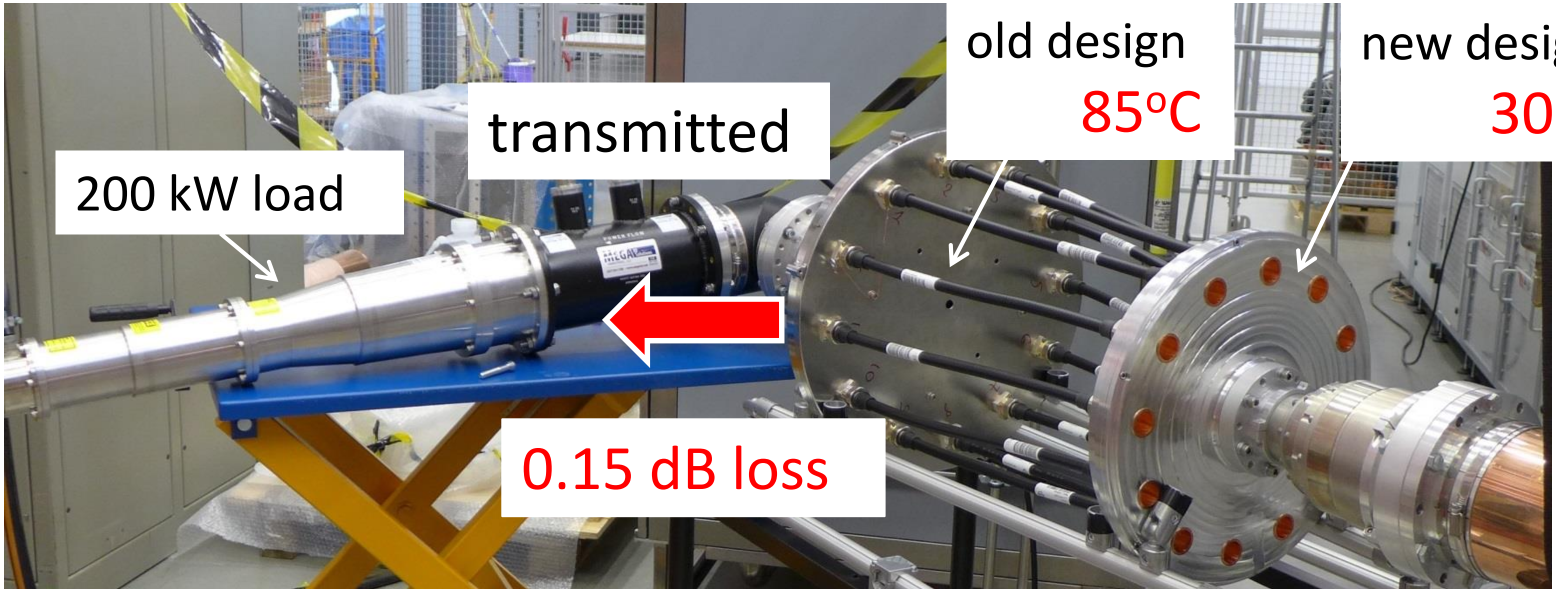
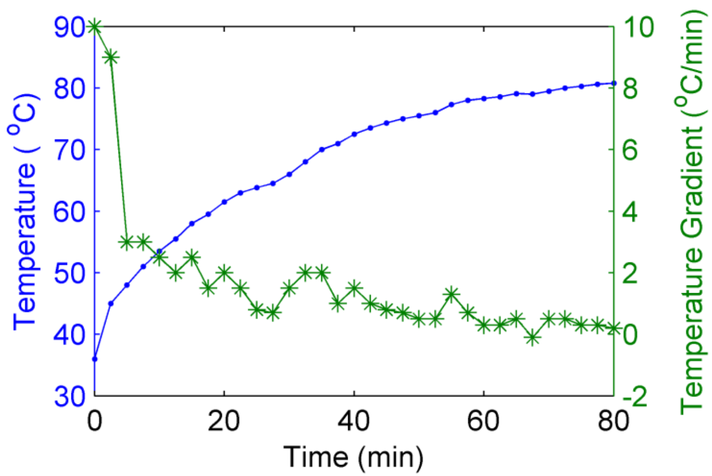
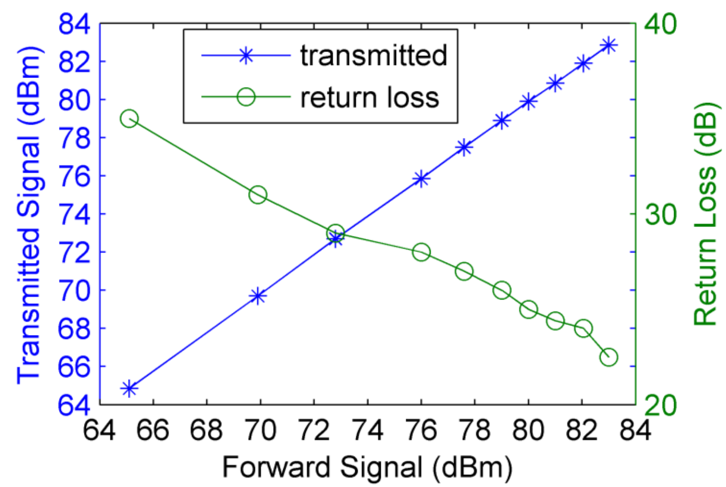
High power splitter/combiner 1:12
RF and thermal characterization at 200 kW



forward

reflected





Summary and Info

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