The European Spallation source in Lund

Frank Gerigk, CERN

Material from: Mats Lindroos, Head of accelerator

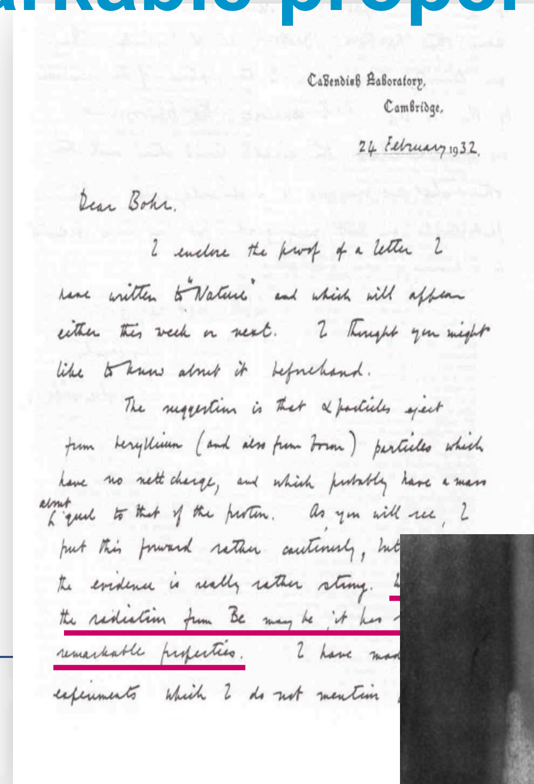
30 October 2014, CERN, Swedish Teachers Programme

Content

- Neutron science
- ESS
- ESS accelerator
- ESS target
- Summary movie

“Whatever the radiation from Be may be it has most remarkable properties”

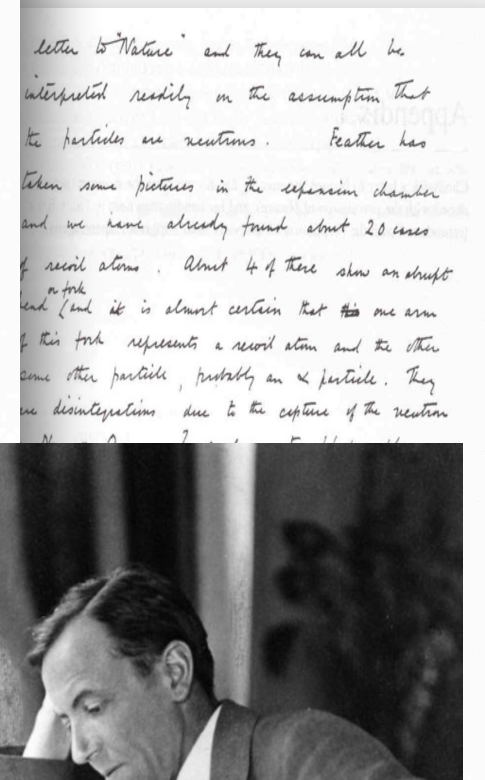
Neutron discovery
James Chadwick
1932
(α,n) reaction
Nobel price 1935

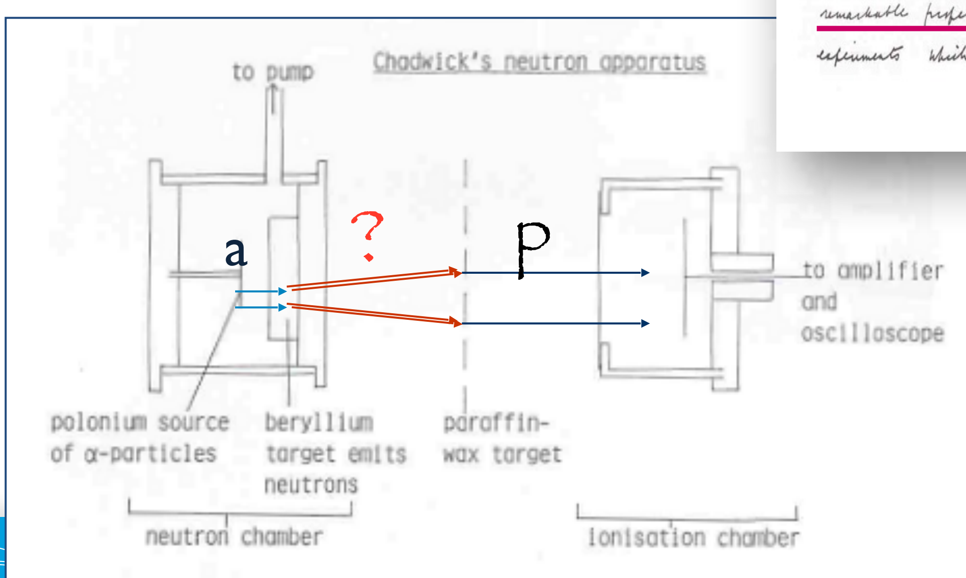

Cavendish Laboratory,
Cambridge.
24 February 1932.

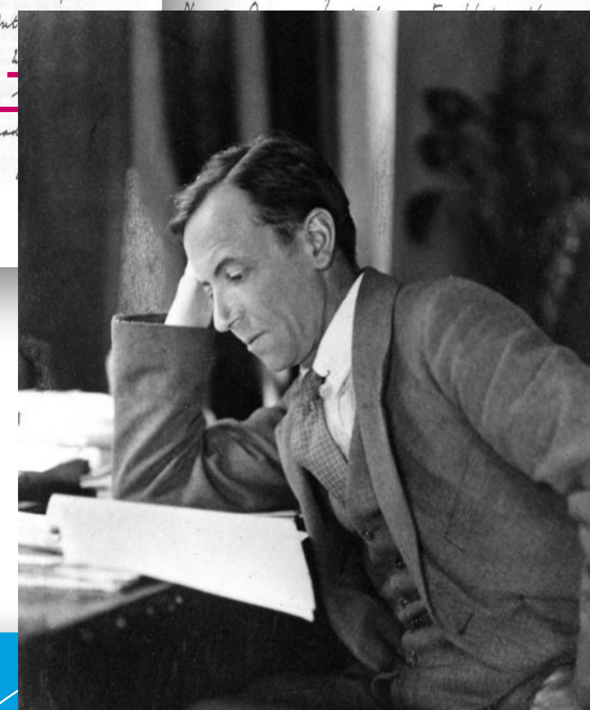
Dear Bohr,

I enclose the proof of a letter I have written to "Nature" and which will appear either this week or next. I thought you might like to know about it beforehand.

The suggestion is that α particles eject from beryllium (and also from boron) particles which have no nett charge, and which probably have a mass about equal to that of the proton. As you will see, I put this forward rather cautiously, but the evidence is really rather strong. ... the radiation from Be may be, it has ... remarkable properties. I have ... experiments which I do not mention ...


letter to "Nature" and they can all be interpreted readily on the assumption that the particles are neutrons. Feather has taken some pictures in the expansion chamber and we have already found about 20 cases of recoil atoms. About 4 of these show an abrupt end in fork (and it is almost certain that one arm of this fork represents a recoil atom and the other some other particle, probably an α particle. They are disintegrations due to the capture of the neutron ...



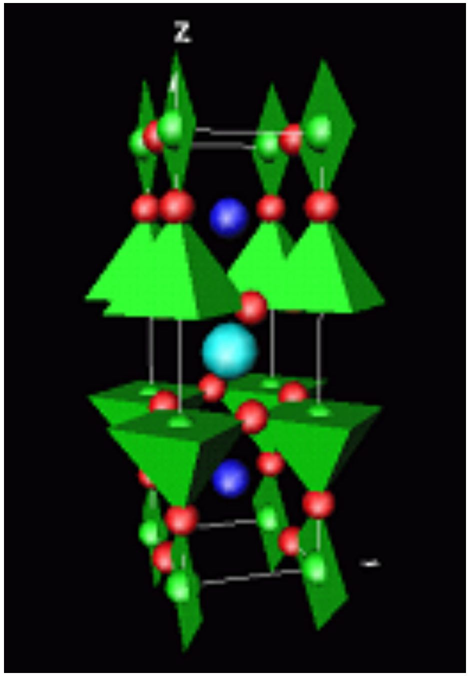


Diffractometers - Measure structures – Where atoms and molecules are

precision: (0.1 - 1 nm)

1 - 10 Ångström hydrogen atom diameter: 0.25 A

Analysing the structure of material from the scattering pattern when a neutron beam interacts with it.



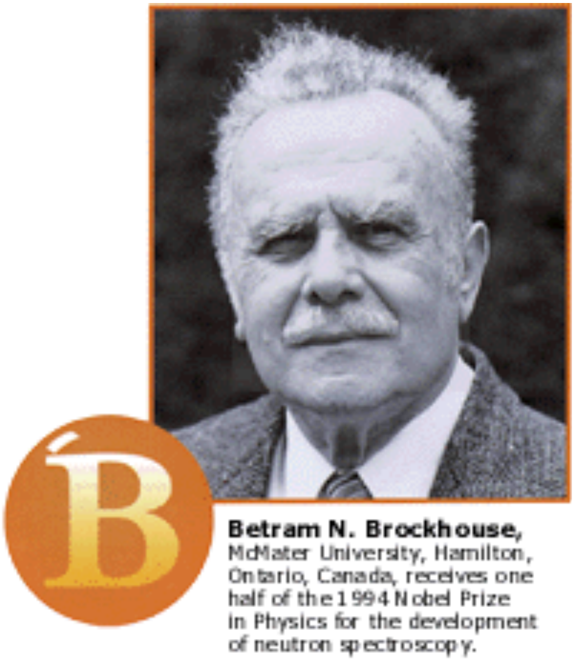
Spectrometers - Measure dynamics – What atoms and molecules do

Resolution:

1 - 80 meV

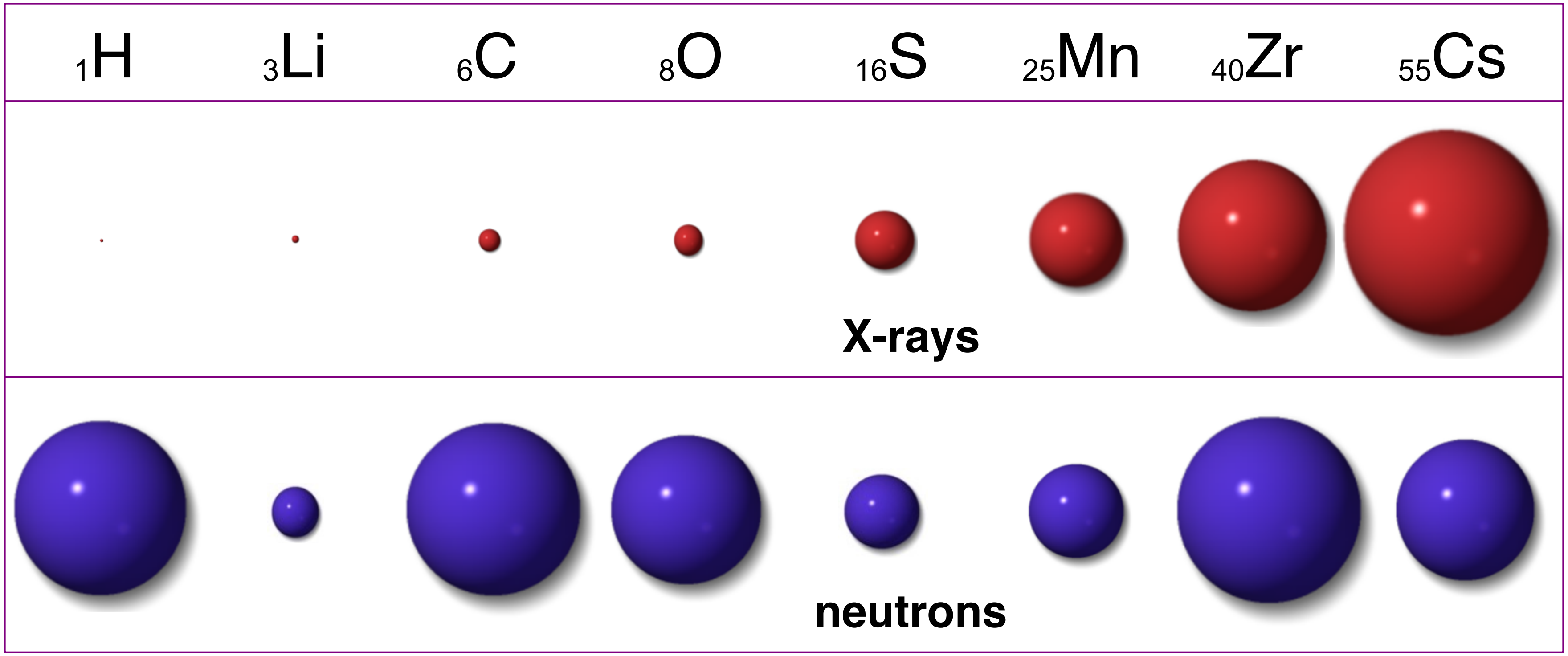
Neutron spectroscopy -
measure the atomic and magnetic motions of atoms

Shared Nobel Price in Physics 1994



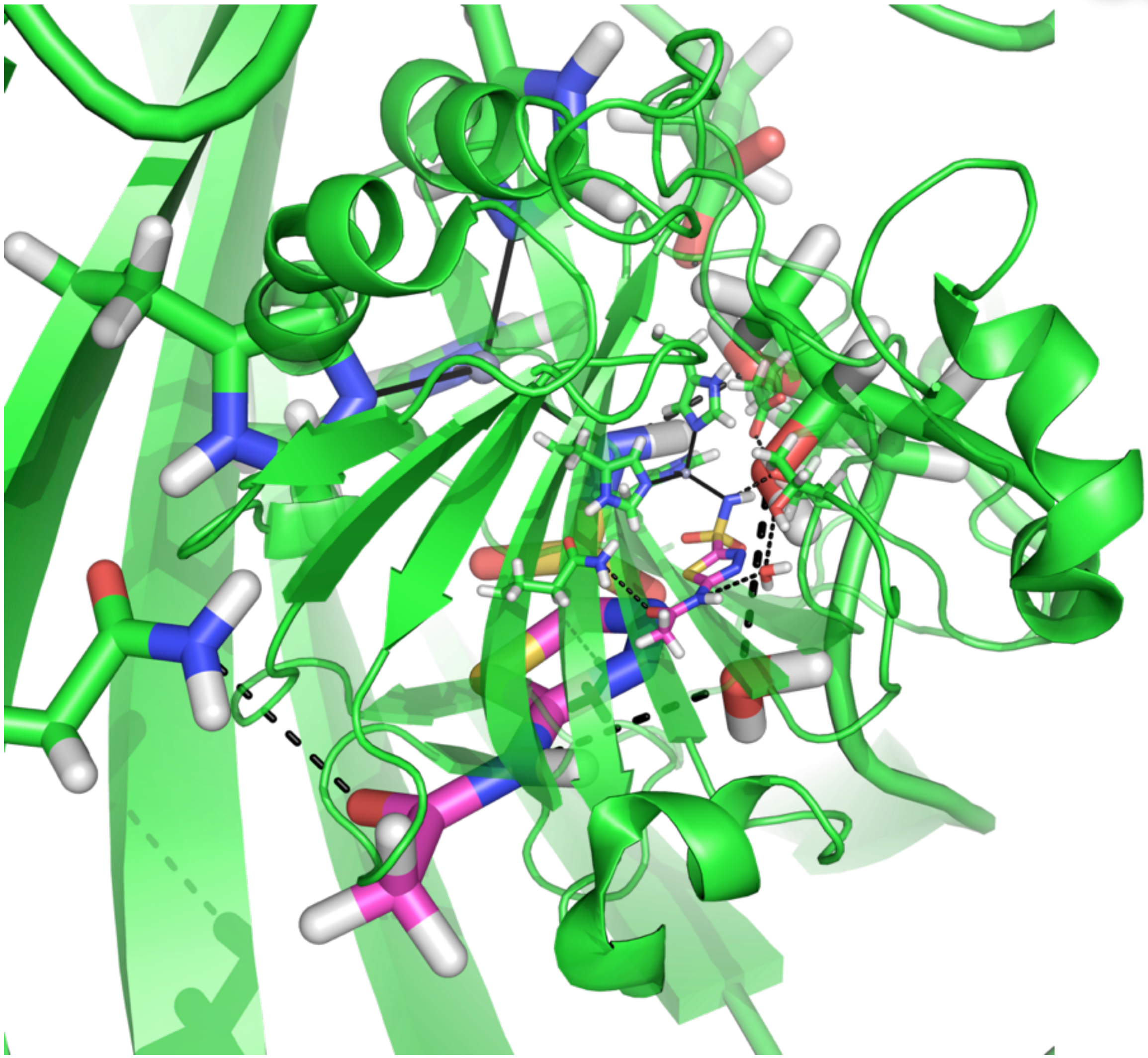
for the development of neutron scattering techniques for staying condensed matter.

X-ray light vs neutrons



High sensitivity for light elements!

Better drugs from detailed protein maps



This enzyme transports CO_2 and regulates blood pH.

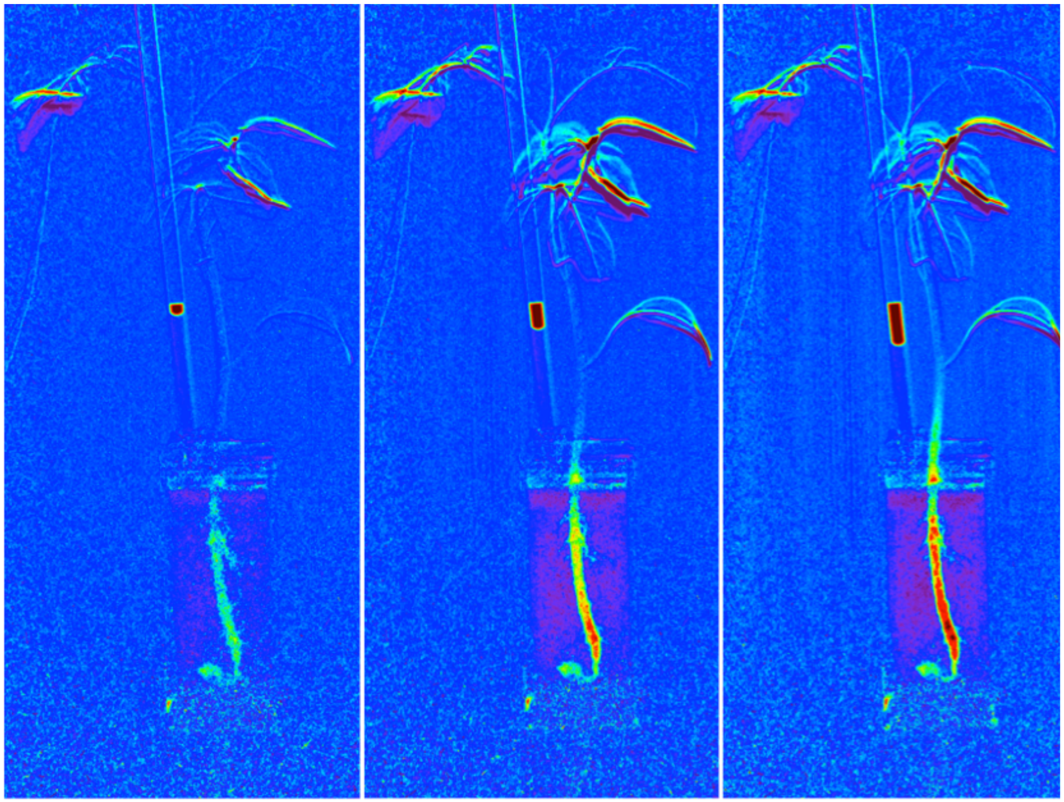
It is a major player in some cancers, glaucoma, obesity and high blood pressure

Neutron crystallography pinpoints protons and waters, showing how the drug Acetazolamide binds

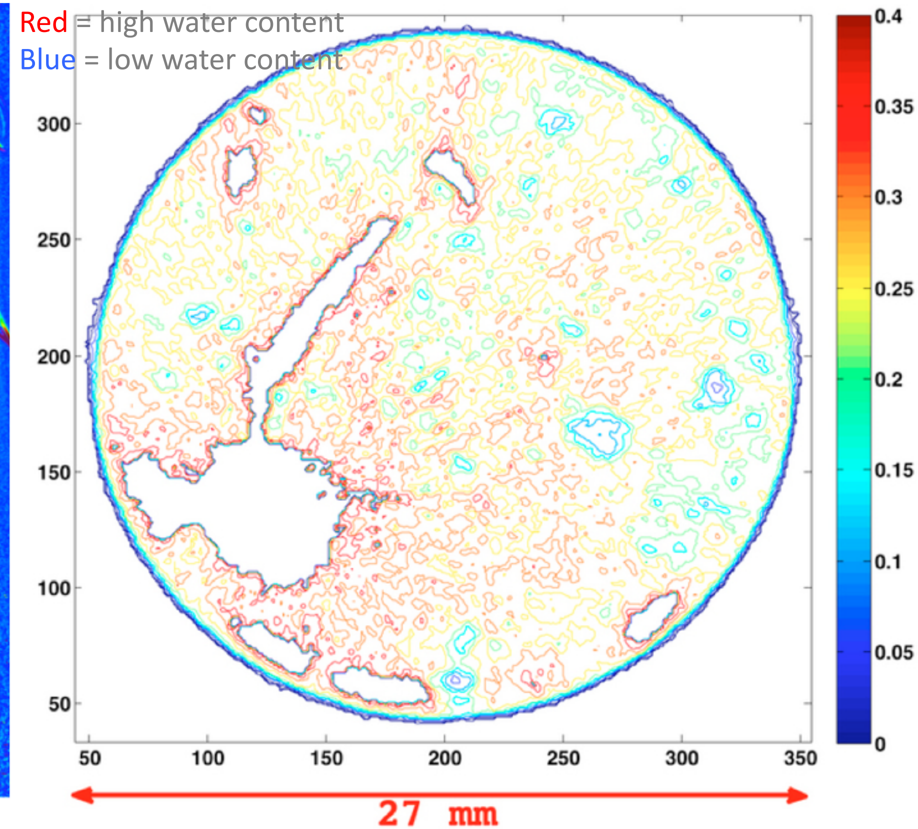
10^{-9} m

Fisher, S. Z. *et al*. 2012 JACS

Whole-organism neutron imaging



Visualising water flow in a tomato seedling with neutron imaging.



Cross-section of plant roots in soil shows that plants collect reservoirs of water around their roots.

Matsushima U. *et al.* 2008 (WCNR-8), Gaithersburg, USA

Paul Scherer Institute

17 nations committed to build ESS

Cash contributions from Sweden, Denmark and Norway
50% of construction and 15-20% of operations costs

In-kind contributions from the other 14 nations

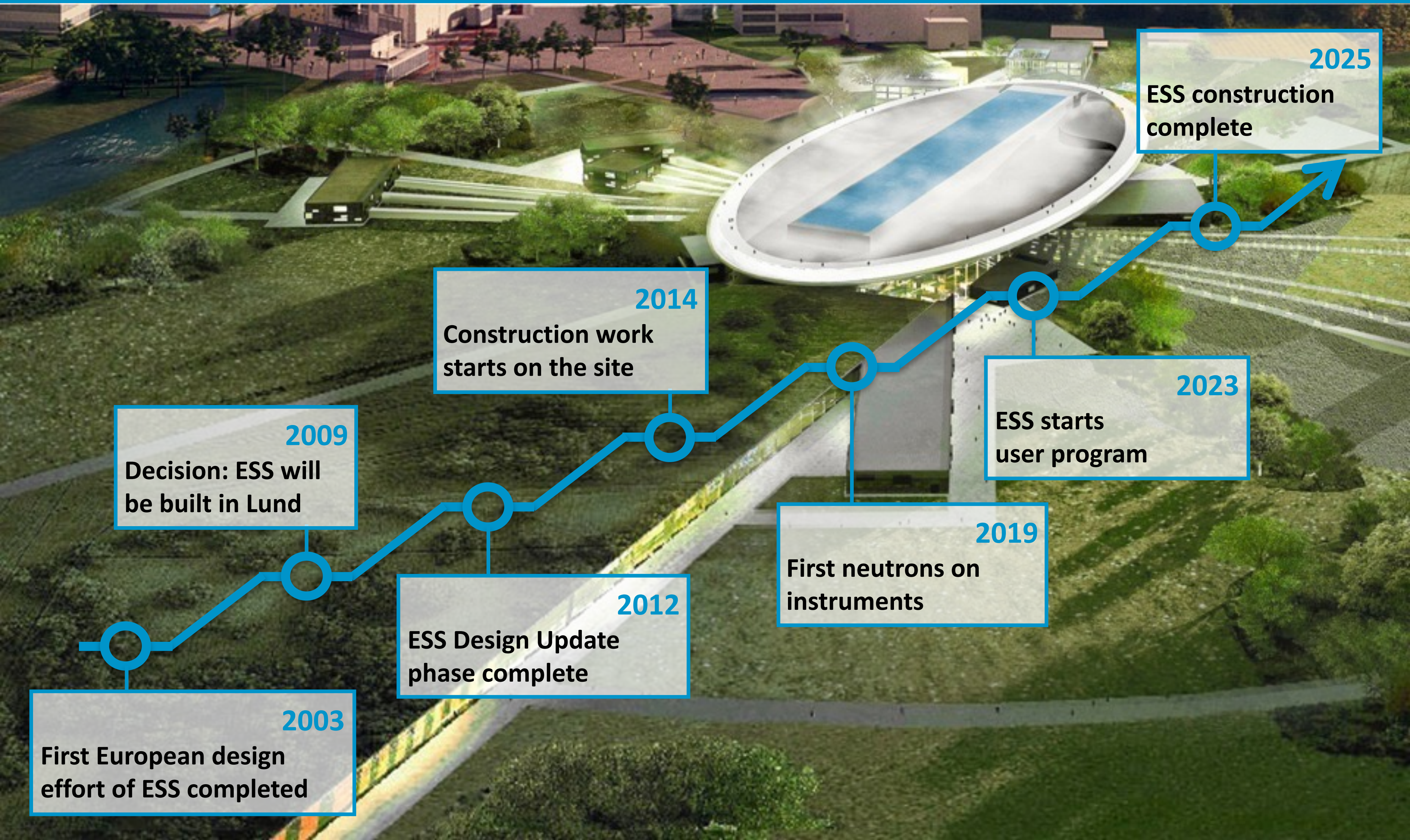
Construction cost: 1843 M€
Operation cost: 140 M€
Decommissioning cost: 177 M€

ESS AB 2014, ca 250 people, 32 nationalities

EUROPEAN SPALLATION SOURCE

Road to realising the world's leading facility for research using neutrons

EUROPEAN SPALLATION SOURCE



An accelerator-based neutron source

Accelerator
accelerate protons to 2.2 GeV to create 5 MW (average power), 14 Hz beam pulses

→

Target
fast neutrons are released from the target material (tungsten)

Moderator
slow down the neutrons to energies, which are needed for the scattering instruments

→

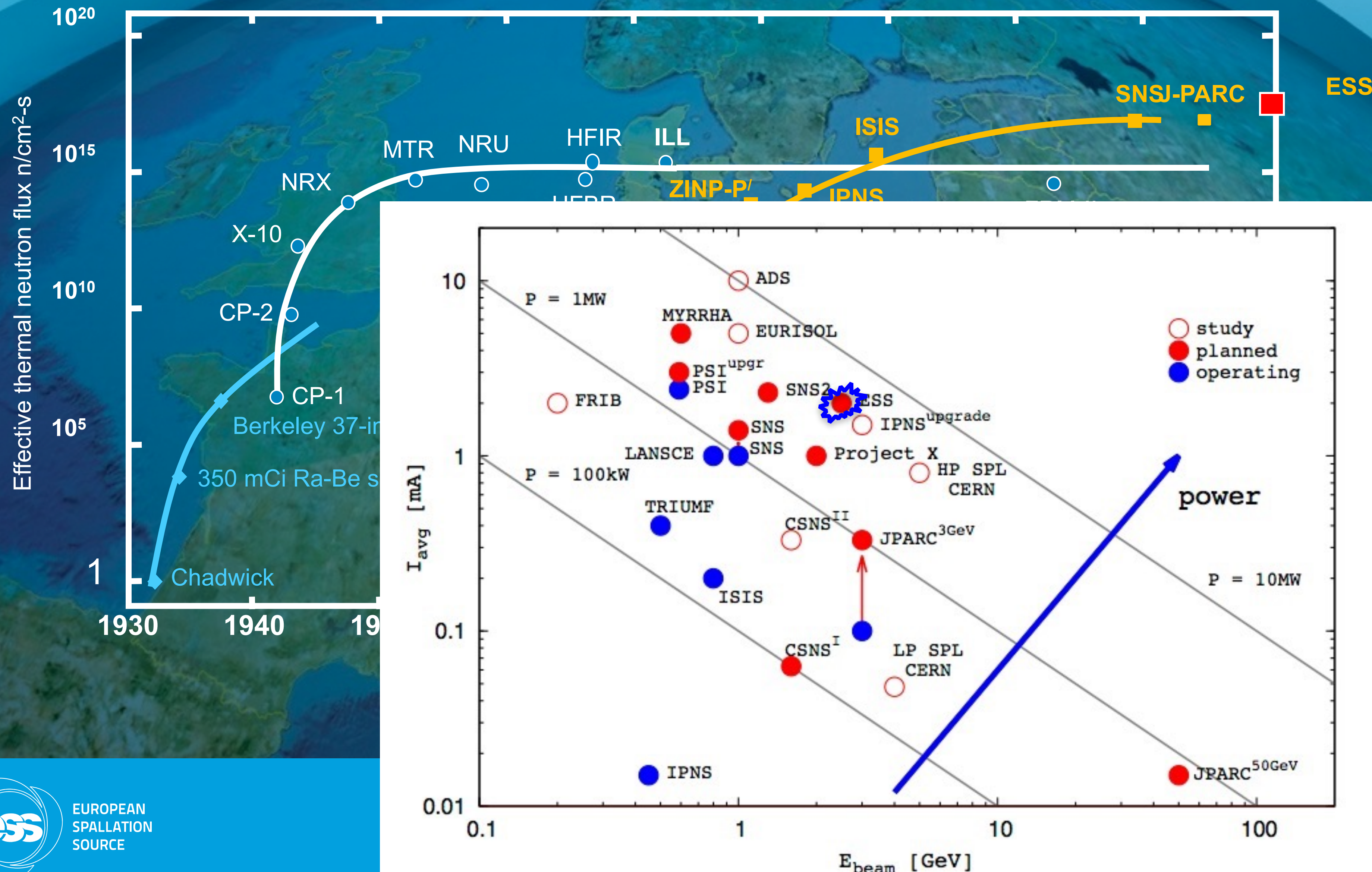
Neutron guides
ducts transport the neutrons to the scientific instruments

Instruments
neutrons are scattered by an object and the direction, intensity and/or velocity of the scattered neutrons give information about atomic position and motion (and about magnetic fields)

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!!!

ESS - Bridging the neutron gap



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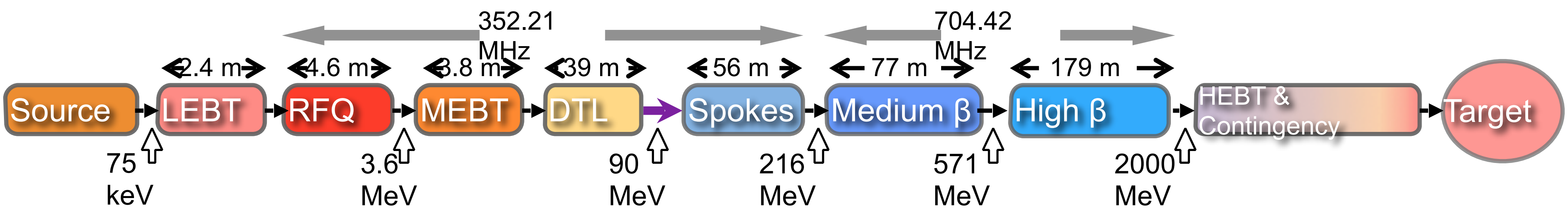
Build and operate a 5 MW SCRF linac

Design Drivers:

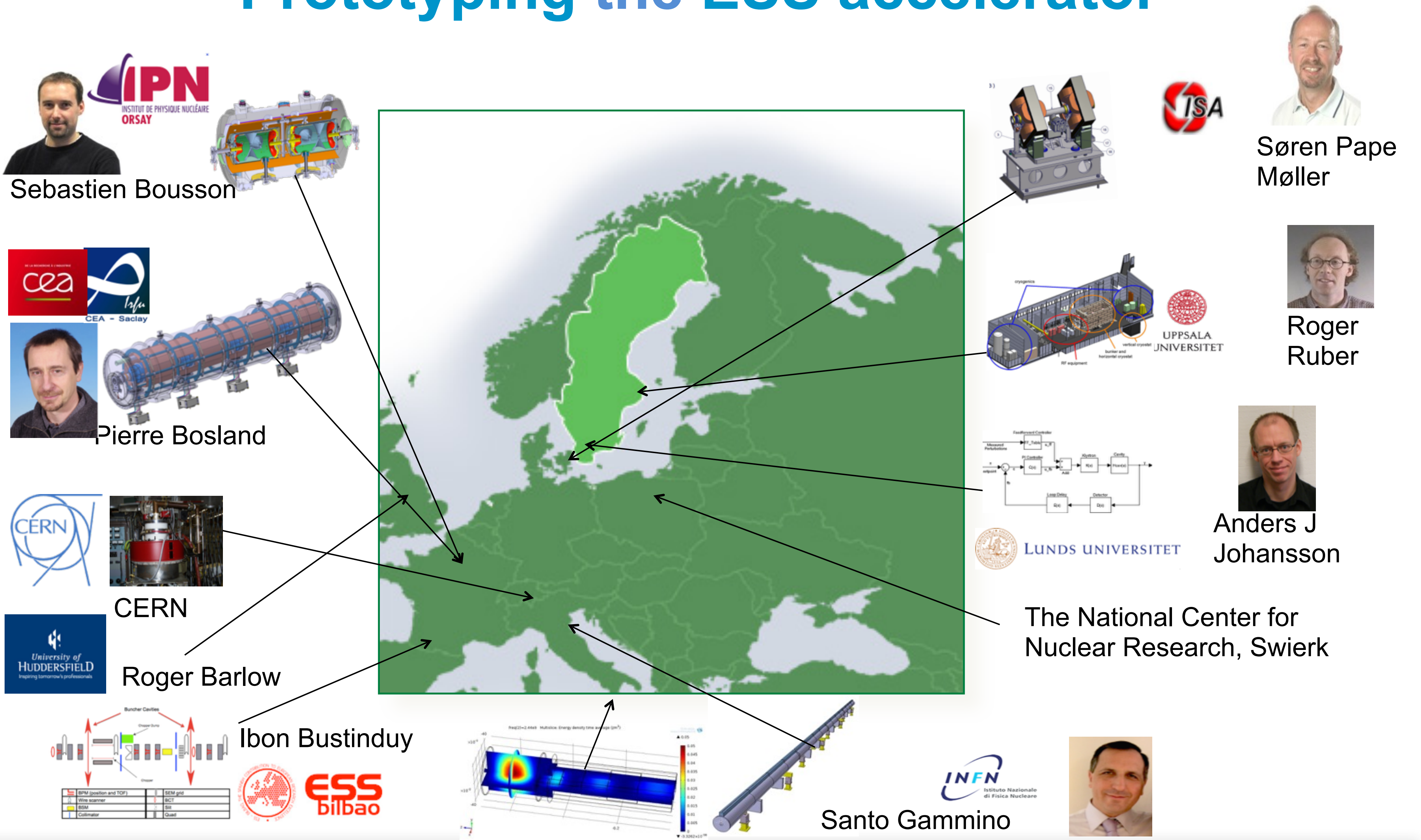
- High Average Beam Power: 5 MW
- High Peak Beam Power: 125 MW
- High Availability: > 95%

Key parameters:

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

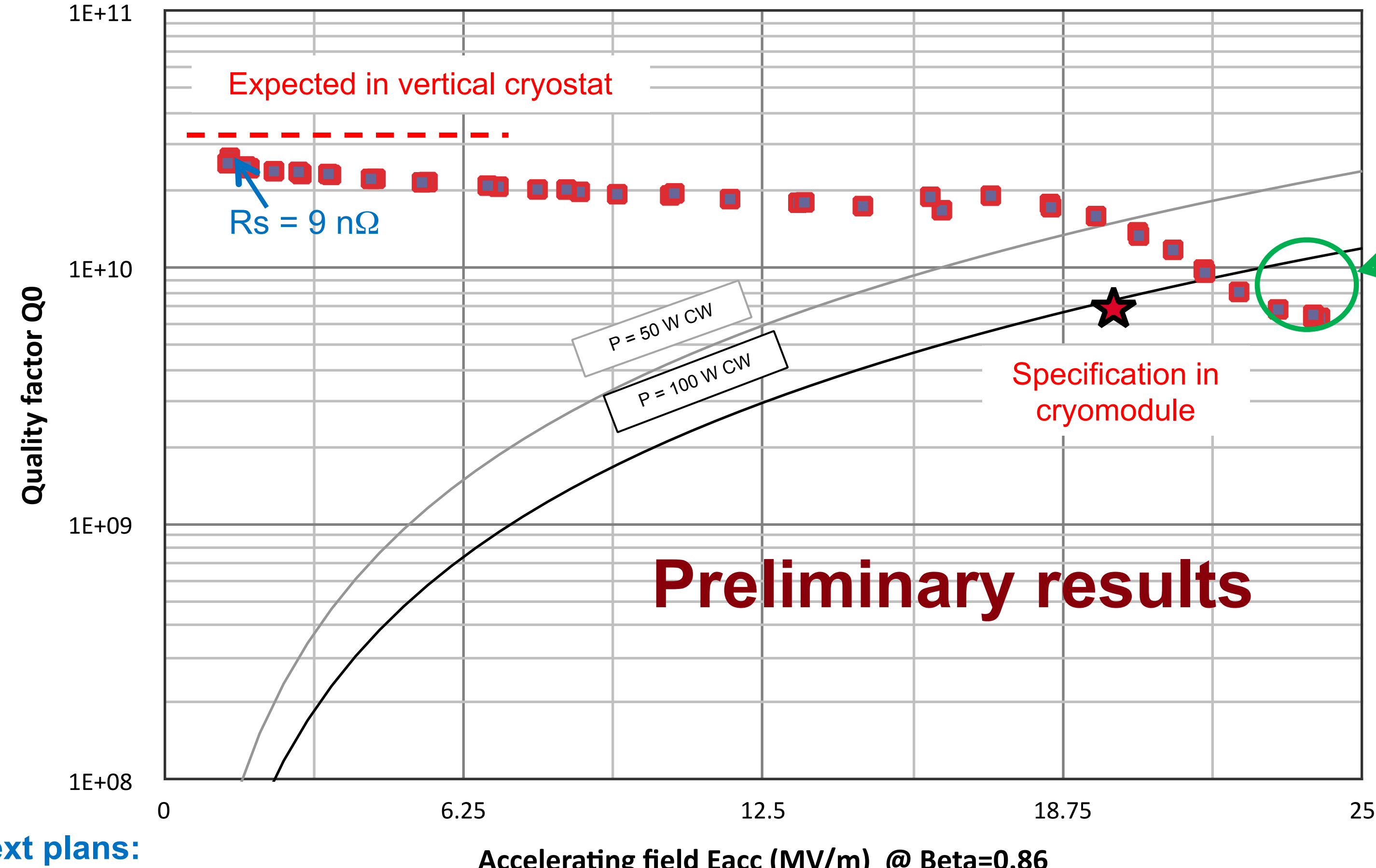


Prototyping the ESS accelerator



FIRST COLD TEST RESULT OF FIRST ESS HIGH BETA PROTOTYPE CAVITY

- Measurements done the 22th of May 2014 in vertical cryostat at CEA Saclay
- Testing conditions: CW mode
- Operating temperature: 2 K
- Resonant frequency of π mode (measured): 704.292788 MHz
- External coupling (measured) : Q_i = 6.5e9 ± 1e9, Q_t = 6.8e12
- Parameters used : G = 241, R/Q = 435.35 Ω (at β = 0.86), L_{acc} = 0.92 m



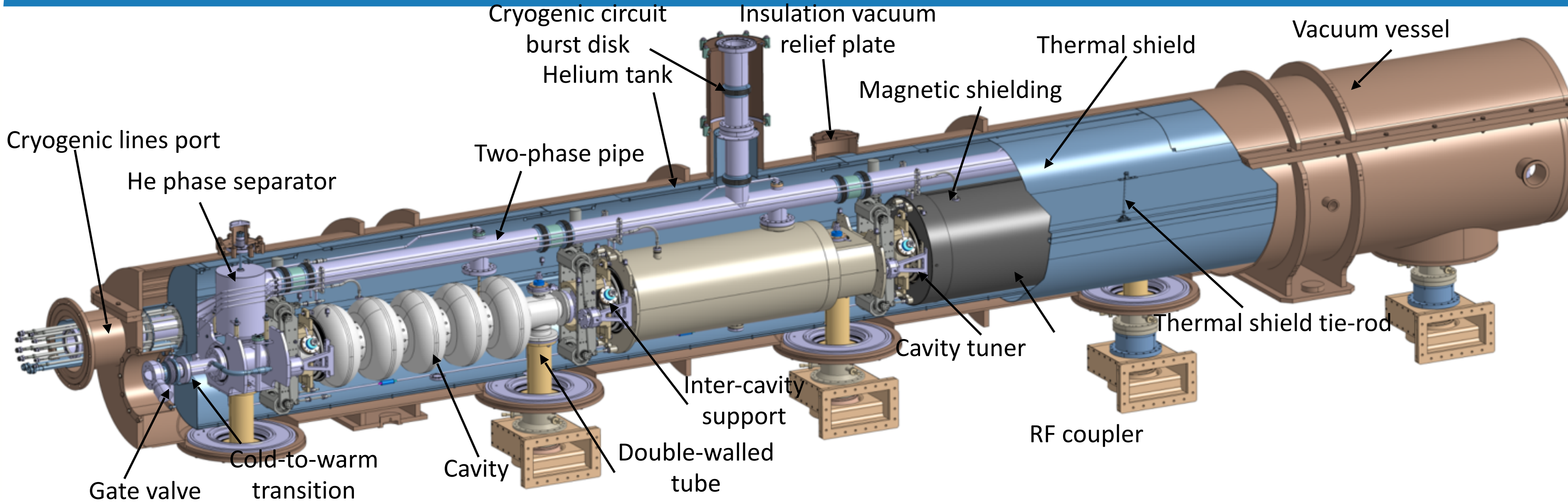
Test limited by RF amplifier (saturation at 190 W) and high X-ray level

☞ No quench observed

Next plans:

- Measurement of 1st bandpass mode at 2K
- Measurement of resonant frequency of HOM at 2K
- If possible, increase accelerating field up to the quench limit
- Perform heat treatment at CERN at 650°C under vacuum

CERN cryo-module development
collaboration with ESS, IN2P3, CEA Saclay



- Stainless steel helium tanks (first one under test)
- Power coupler as supporting element (under test with a dedicated mock-up)
- Cryo-module ordered and expected for April 2015

1-50 Hz Modulator

Ampegon (PPT)

U_k	-110
I_k	25 A
P_{pulse}	2.6
f_{rep}	1-50
Z_k	4.4
$T_{pulse}/$	1/0.8
droop	1%

- Modulator procured & supplied by ESS within SPL/ESS collaboration. 7/2011 call for tender - 5/2014 reception at CERN.
- Based on simple LR bouncer topology. Av. power limited to 160 kW.
- 704 MHz klystron (Thales) bought by CERN.

High Power IOT development

Collaboration ESS/CERN-SPL

CERN 801 MHz
60 kW CW
IOT amplifier

Draft specifications

Parameters	Proposed value
Frequency	704.42 MHz
Bandwidth	>1 MHz @ -1 dB
Peak Power	750 kW alt 1.5 MW
Pulse length	Up to 4 ms
Repetition rate	with respect to maximum
Duty cycle	10 % duty cycle
High Voltage	Maximum 50 kV
Efficiency DC to RF	> 65 %
Gain	23 dB
Harmonic content	< -30 dBc, 2^{nd} & 3^{rd} harm
Max collector dissipation	115 kW average alt 230 kW average
RF input standard	13/30 mm 50 ohm
RF output standard	WR 1150
Insulation	Air

IVEC'13 paper

Applications of High Power Induction Output Tubes in High Intensity Superconducting Proton Linacs

M.R.F Jensen[1], R. Garoby[2], F. Gerick[2], M. Lindroos[1], D. McGinnis[1], E. Montesinos[2], A. Sunesson[1]
(1) European Spallation Source (ESS), Sweden
(2) CERN, 1211-Geneva, Switzerland

Abstract: *Very intense proton sources are being planned at many facilities worldwide. These facilities are based on superconducting radio frequency accelerating structures. The nature of these structures require many power sources with a peak power capability in the 1 MW range with a duty factor on the order of 10%. In the past, the conventional choice for RF power has been klystron based systems. The cost and efficiency of klystron systems has caused a number of accelerator laboratories to consider lower cost and more efficient technologies. This paper will explore the possible use of induction output tubes (IOTs) with a peak power level in the range of 1 MW as an alternative for powering high intensity superconducting proton linacs.*

constructed from many shorter accelerating structures. Since the accelerating gradients are high but the RF losses low, the duty factor can be increased allowing the beam current to be reduced and still achieve the same power on the target. Current high power linac projects and studies include ESS in Lund (Sweden), SPL at CERN (Switzerland) and Project-X in Fermilab (USA).

The high number of cryomodules required for the medium and high β parts of the accelerator, results in a requirement for many pulsed RF sources in the power range from a few 100 kW to about 1.2 MW peak with pulses of a few ms. The RF sources required in the current design of the SC part of the ESS linac are given in Table 1 [1].

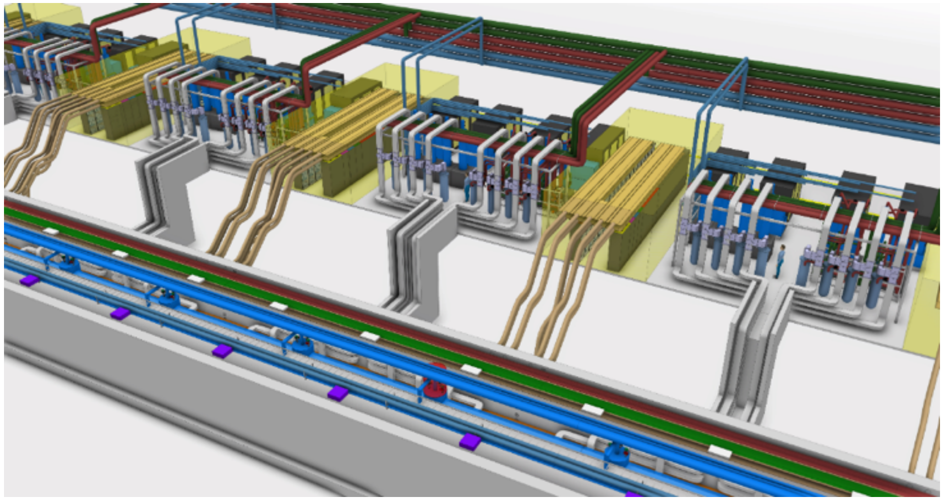
RF Systems

Main features:

- One RF power source (klystron, IOT, ...) per resonator
- Two klystrons per modulator for ellipticals
- Pulsed-cathode klystrons for RFQ, DTL
- Gridded tubes (tetrodes or IOTs) for spokes
- Klystrons for medium-beta ellipticals, and as backup for high-beta
- Developments with industry for high-power IOTs

SNS klystron gallery

	Frequency (MHz)	No. of couplers	Max power (kW)
RFQ	352.21	1	900
DTL	352.21	5	2150
Spokes	352.21	26	350
Medium betas	704.42	32	900
High betas	704.42	88	1100



Layout of ESS linac tunnel and klystron gallery

Target station converts protons to "slow" neutrons

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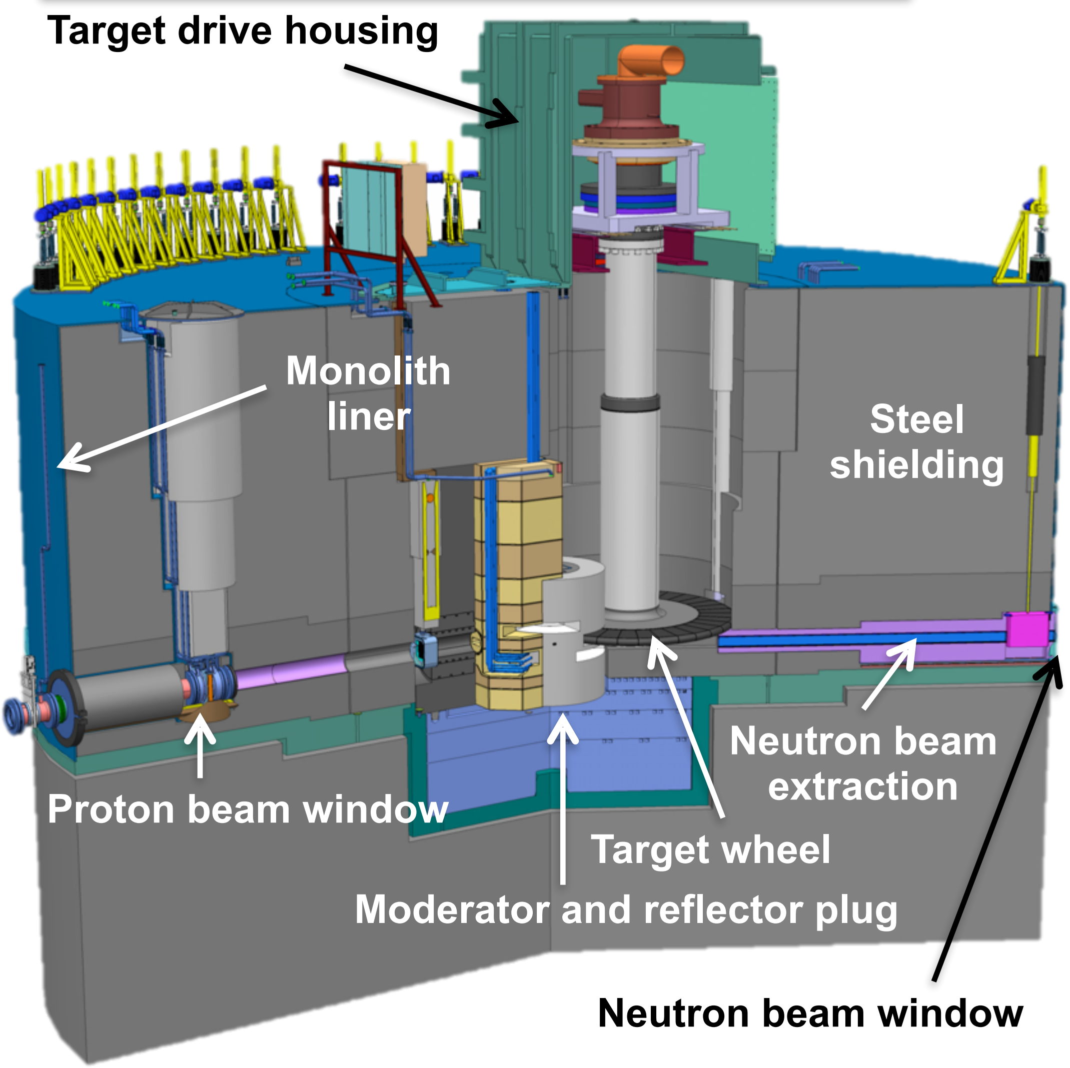
- Diameter ~ 11 m; Height ~ 8 m
- Mass ~ 7000 tonnes (mainly steel)



<u>Functions</u>:

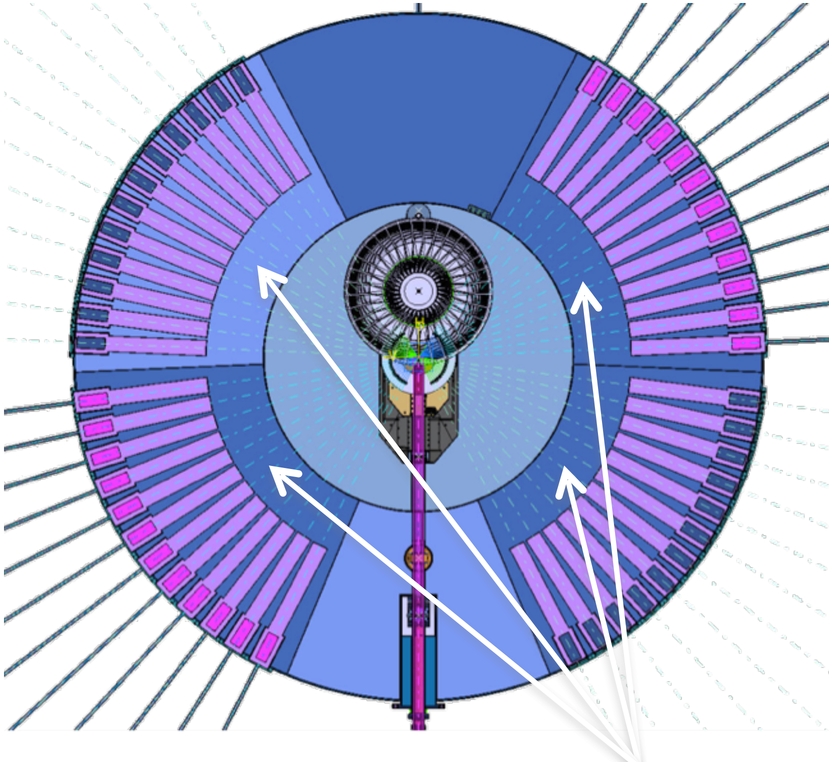
- Convert protons to usable neutrons
- Heat removal
- Confinement and shielding

<u>Unique features</u>:

- Rotating target
- He-cooled W target
- High brightness moderators

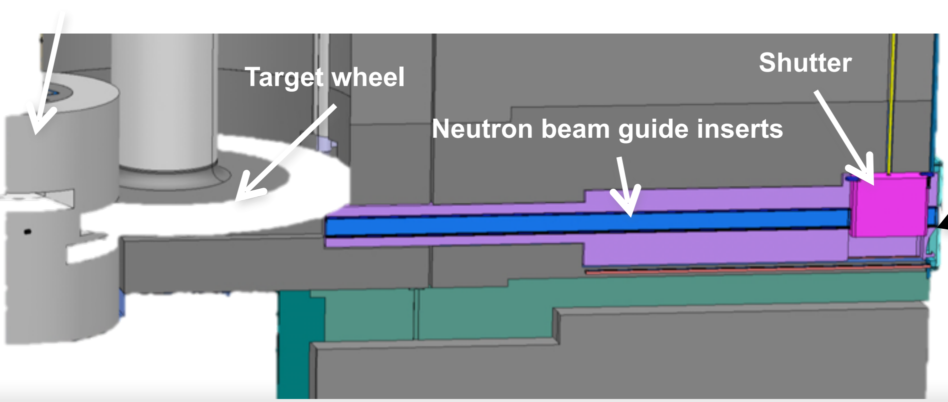
Neutron Beam Extraction

- Neutron beam extraction system design
  - Four 60 degree sectors, whereof
    - Two sectors view the upper moderators
    - Two sectors view the lower moderators
  - In total 48 ports for potential neutron beam line location
  - Neutron beam guide inserts can be located as close as 2 m from the surfaces of the moderators
  - Cut outs in reflectors and shielding for view of the moderators by the neutron beam guide inserts
  - Neutron beam windows separating the monolith helium atmosphere and the ambient atmosphere in the experimental halls



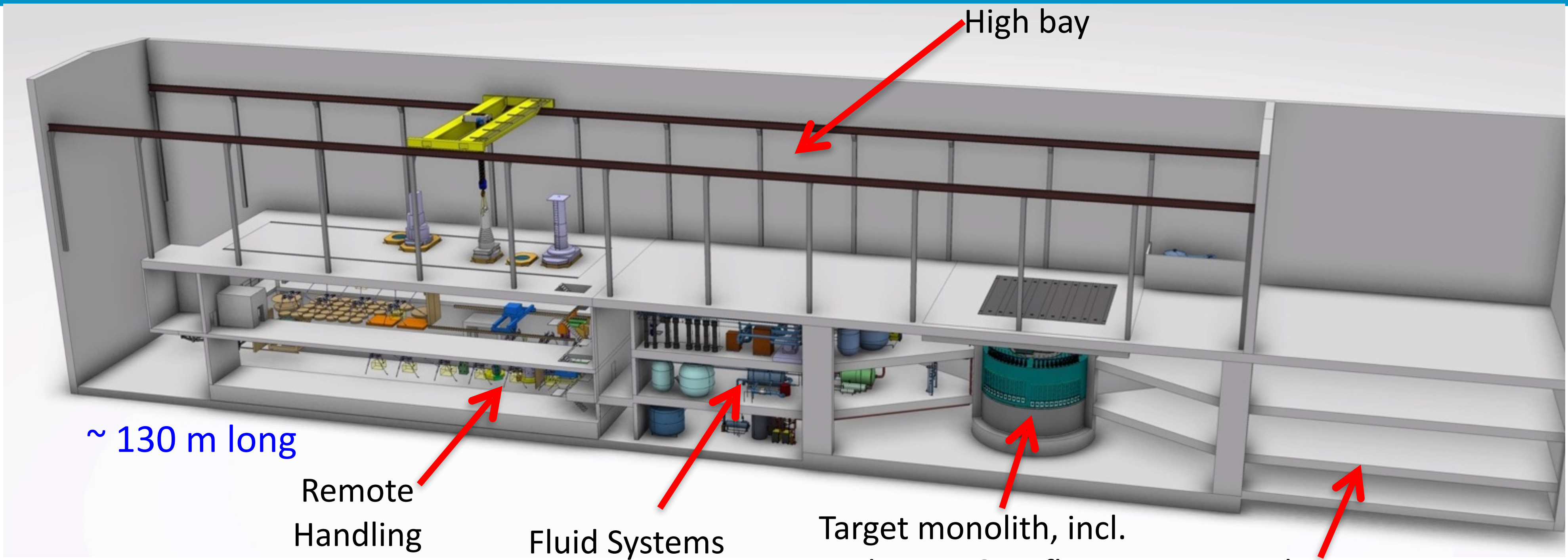
Four 60 degree sectors, each with 12 ports for potential neutron beam positions

Moderator and reflector plug



Neutron beam window

Target Station includes systems that address nuclear hazards



- Remote Handling Systems including hot cells and associated equipment for maintenance and storage of irradiated components
- Target Safety System including credited controls to protect public and environment from radioactive hazard
- Fluid Systems including He and H_2O coolant loops, ventilation, filtering, etc.

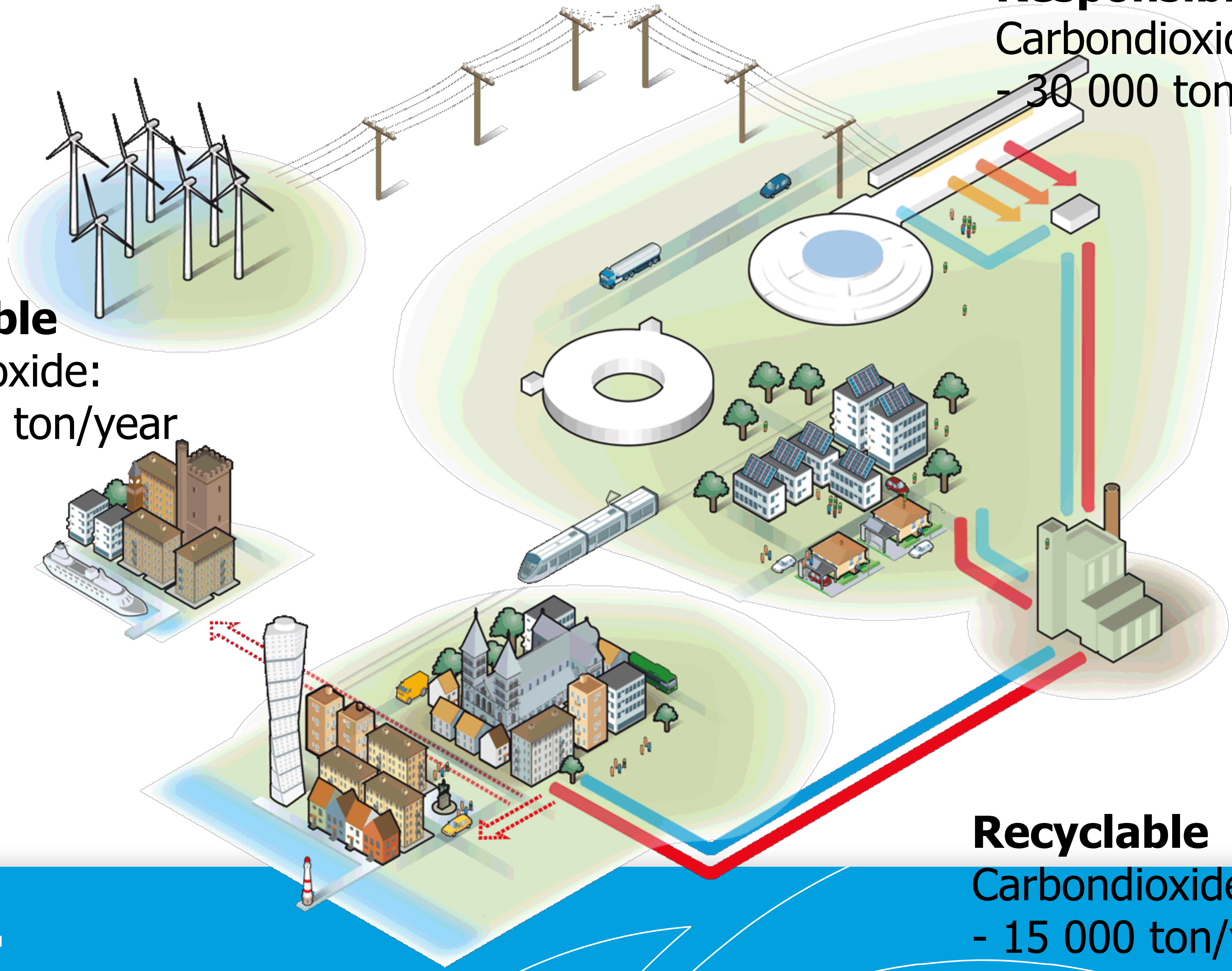
Moderator

- Neutrons collide with particles of similar weight (e.g. hydrogen, water) and loose energy via inelastic scattering.
- ESS will make use of a new innovative “pancake moderator” design, which enhances the beam brightness out of the cold neutron moderators by a factor of 2-3, when compared to traditional designs.

A sustainable research facility

Responsible
Carbondioxide:
- 30 000 ton/year

Renewable
Carbondioxide:
- 120 000 ton/year



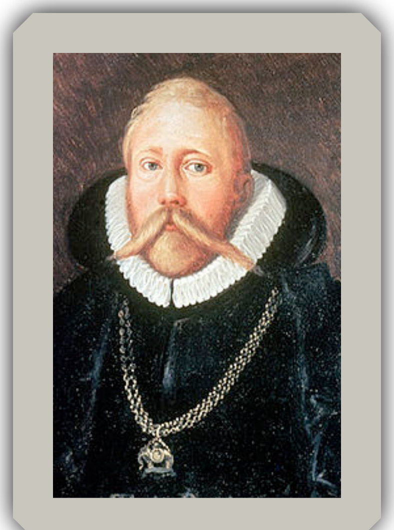
Recyclable
Carbondioxide:
- 15 000 ton/year

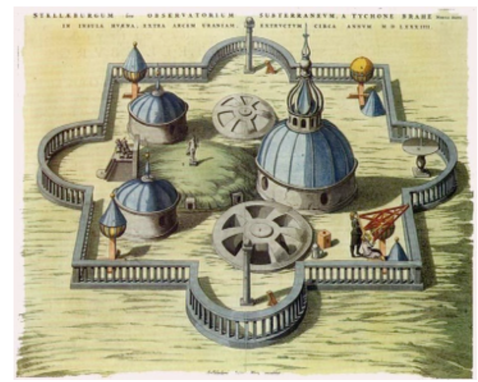
EUROPEAN SPALLATION SOURCE

1.8 Billion Euros:
Biggest investment in Science ever in Scandinavia?

In modern time, definitely YES!

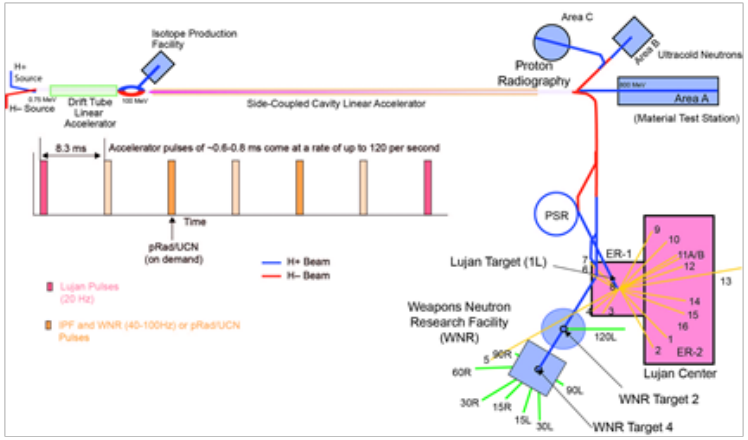
However, Tycho Brahe's observatory (Stjärneborg) costed the Danish king 1% of the state budget in 1580.





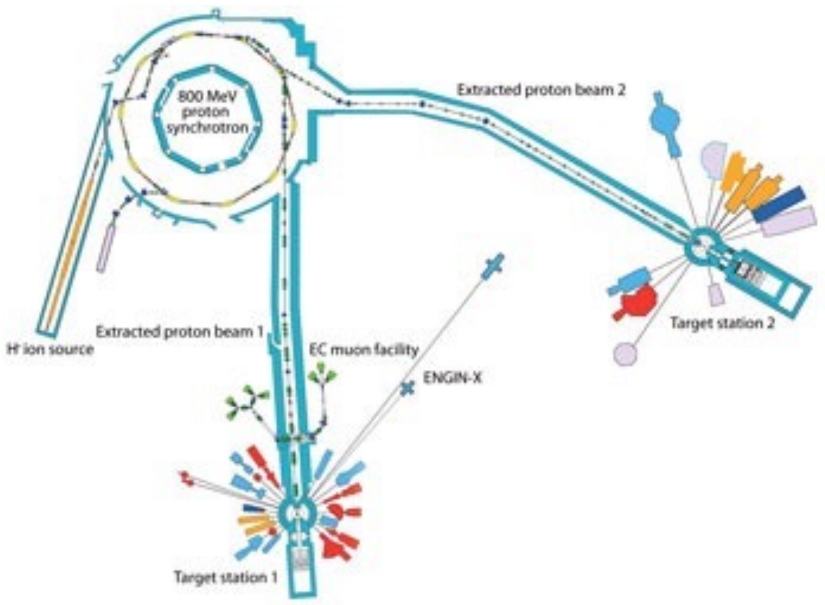
"With better measurements of the stars positions and movements I can make much better horoscopes for you, your majesty!"

Short pulse sources-LANCSE



- LANCSE, NC LINAC /Storage ring, 1972, 100 kW, 800 MeV, 17 mA in linac, 600 ns, 20 Hz
- Examples: Combined H- and H + acceleration

Science & Technology Facilities Council
ISIS

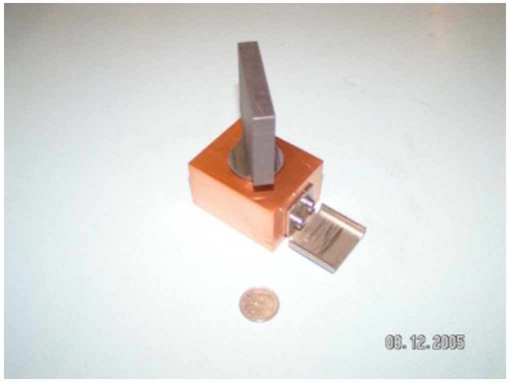


Accelerated intensity at 800 MeV, 160 kW:

2.5×10^{13} ppp - 3.75×10^{13} ppp

(200 μA) (300 μA)

- Neutron scattering facility
- Two target stations
- Muon facility



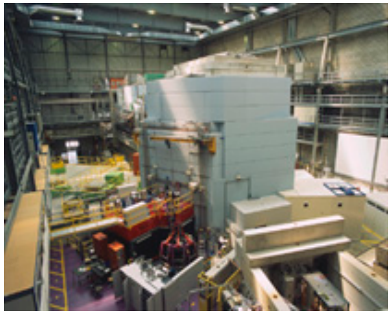
Examples of challenges: Ceramic vacuum chambers, high space charge synchrotron

EUROPEAN SPALLATION SOURCE

Short pulse neutron sources-SNS

- SNS, SC LINAC/Storage ring, 2007, 1.4 MW, 1 GeV, 26 mA in linac, 627 ns long pulse, 60 Hz
- Examples of challenges: Better understand stripping reaction in linac, accumulation in storage ring

Existing facilities

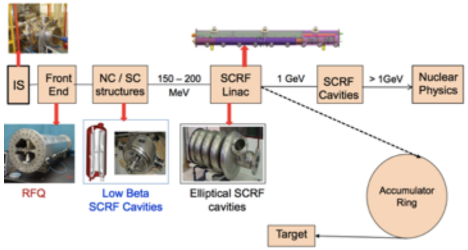


SINQ, Switzerland
1997–
Cyclotron
590 MeV, CW
2.2 mA extracted
1.3 MW

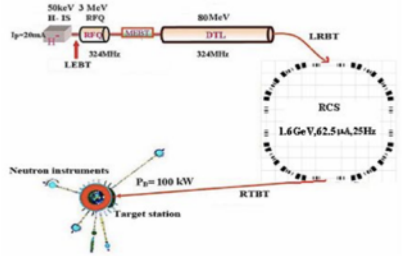
Figure 2 Overall image of J-PARC

J-PARC, Japan
2008–
RCS
3 GeV, short pulse
330 mA extracted
1 MW (planned)

planned facilities



ISNS, India
Linac+ring
1 GeV, short pulse
20–50 mA in linac
1 MW



CSNS, China
2018–
RCS
1.6 GeV, short pulse
15 mA in linac
100 kW

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Summary movie