European Spallation Source

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SRF Accelerator

Acceleratorfysik

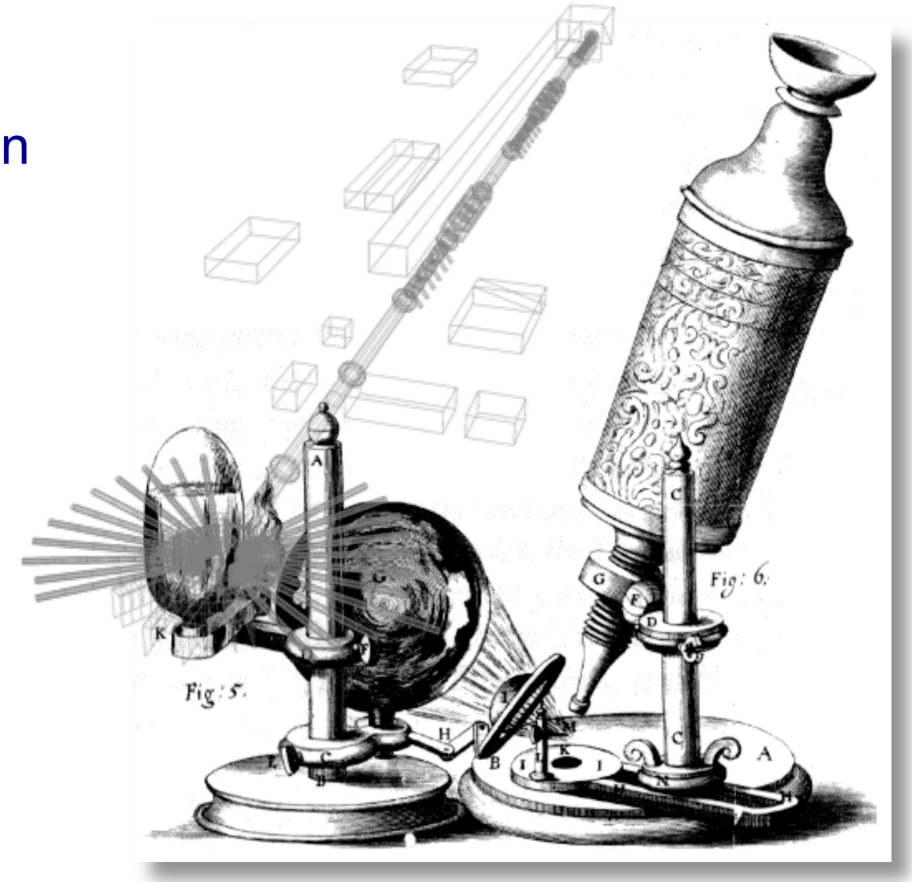
Lund University

www.europeanspallationsource.se

Lund, 13 November 2014

Outline

- Science for society and spallation
- ESS project and infrastructure
- Few accelerator components



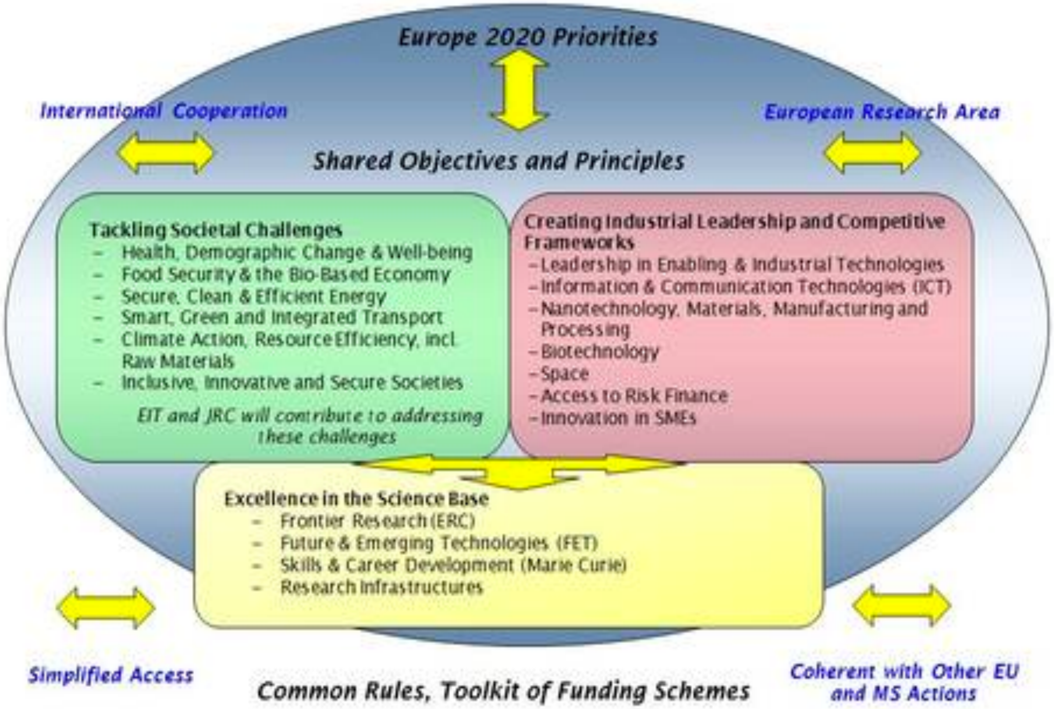
Acknowledgment:
Mats Lindroos, David McGinnis and Aurelien Ponton

Life Science and Society

EU Horizon 2020 – strategy

The structure which the EC proposed consists of three basic priorities:

1. **Excellent Science**
2. **Industrial Leadership**
3. **Societal Challenges**



Scientific challenges

Solid State Physics

Dynamics of superlattices, wires and dots, molecular magnets, quantum phase transitions

Liquids and Glasses

Solvent structures, influence of molecular structures on protein folding

Fundamental Physics

Left and right handedness of the universe, neutron decay, ultracold neutrons

Soft Condensed Matter

Time resolution, molecular rheology, structures and dynamics

Biology and Biotechnology

Hydrogen and water , membranes, biosensors, functions

Materials Science and Engineering

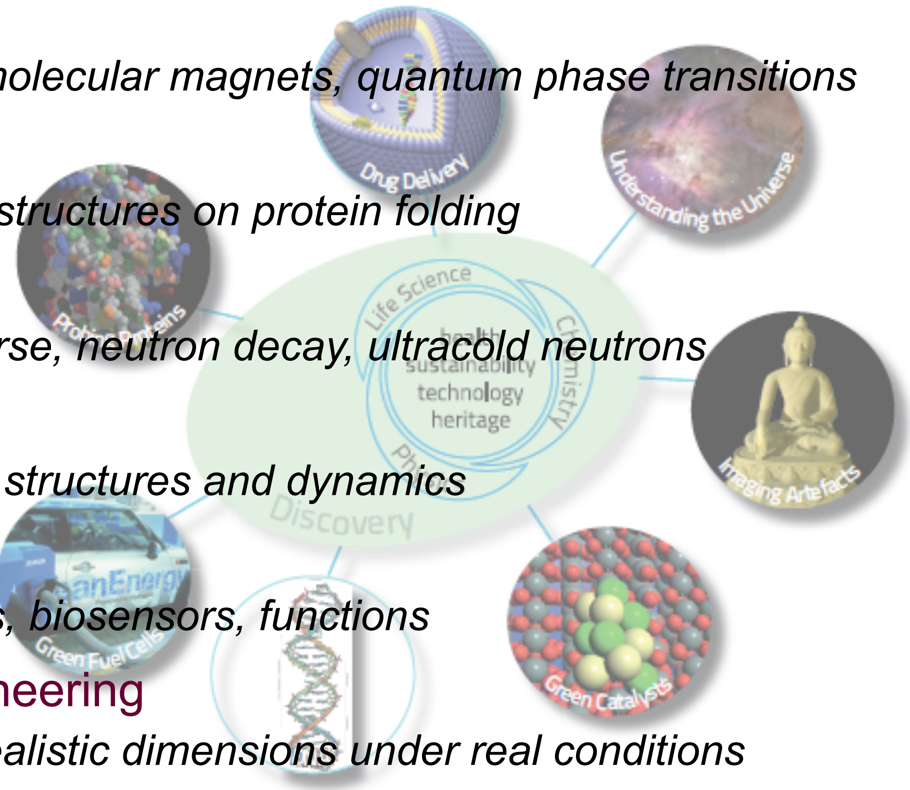
Real time investigations with realistic dimensions under real conditions

Chemical Structure, Kinetics and Dynamics

Thin films, pharmaceuticals, supramolecules - structures and functionality

Earth and Environmental Science, Cultural Heritage

Extreme temperatures and pressures simulating the mantle



Why neutrons as a probe ?

Electrically neutral – neutrons are non-destructive and can penetrate deep into matter. This makes them an ideal probe for biological materials and samples under extreme conditions of pressure, temperature, magnetic field or within chemical reaction vessels. 

Microscopically magnetic – they possess a magnetic dipole moment which makes them sensitive to magnetic fields generated by unpaired electrons in materials. Precise information on the magnetic behavior of materials at atomic level can be collected. In addition, the scattering power of a neutron off an atomic nucleus depends on the orientation of the neutron and the spin of the atomic nuclei in a sample. This makes the neutron a powerful instrument for detecting the nuclear spin order. 

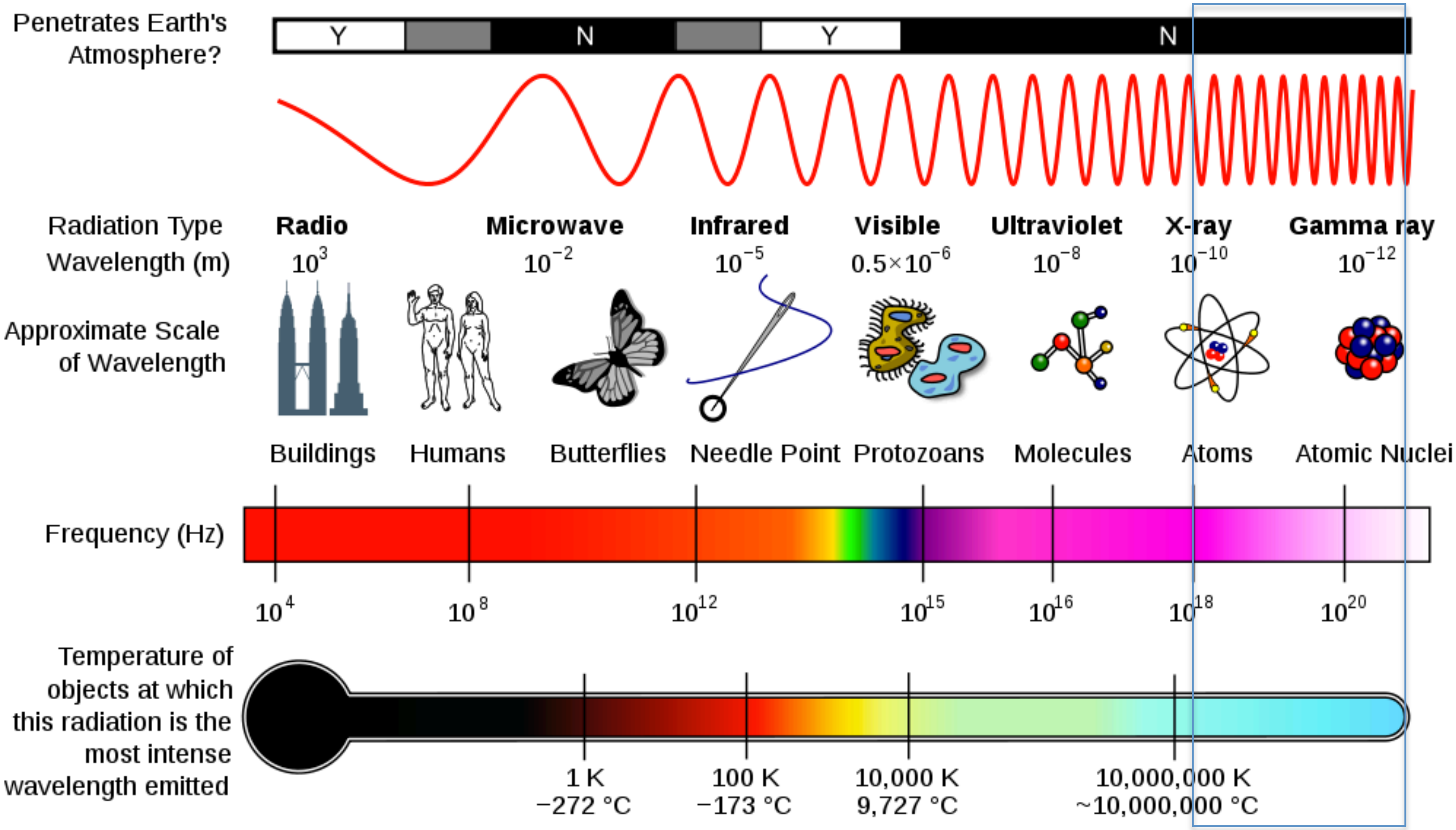
Ångstrom wavelengths – neutron wavelengths range from 0.1 Å to 1000 Å, making them an ideal probe of atomic and molecular structures, be they single atomic species or complex biopolymers. 

Why neutrons as a probe ?

Energies of millielectronvolts – their energies are of the same magnitude as the diffusive motion in solids and liquids, the coherent waves in single crystals (phonons and magnons), and the vibrational modes in molecules. It is easy to detect any exchange of energy between a sample of between 1microeV (even 1 neV with spin-echo) and 1eV and an incoming neutron.

Randomly sensitive – with neutrons the variation in scattering power from one nucleus to another within a sample varies in a quasi-random manner. This means that lighter atoms are visible despite the presence of heavier atoms, and neighboring atoms may be distinguished from each other. In addition, contrast can be varied in certain samples using isotopic substitution (for example D for H, or one nickel isotope for another); specific structural features can thus be highlighted. The neutron is particularly sensitive to hydrogen atoms; it is therefore a powerful probe of hydrogen storage materials, organic molecular materials, and biomolecular samples or polymers.

Electro-magnetic Spectrum & Neutron Microscope



Boltzmann distribution

$$E = k_B T$$

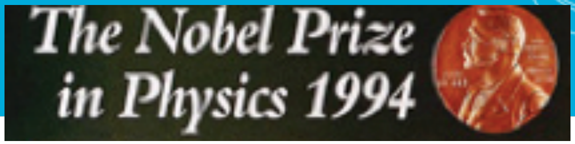
$$E = k_B T = \tfrac{1}{2} m v^2 = \frac{h}{2m\lambda^2}$$

$$\lambda = \frac{h}{mv}$$

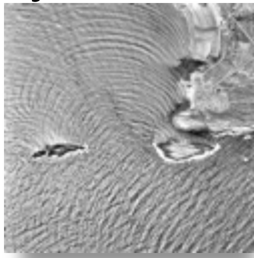
De Broglie

$$E\,[meV] = 0.0862\,T\,[K] = 5.22\,v^2\,[km/s] = 81.81\frac{1}{\lambda^2}\,[A]$$

Why neutrons as a probe ?



In half a century, neutron scattering science has developed enormously with an effective gain in source performance of only a factor of 4 !

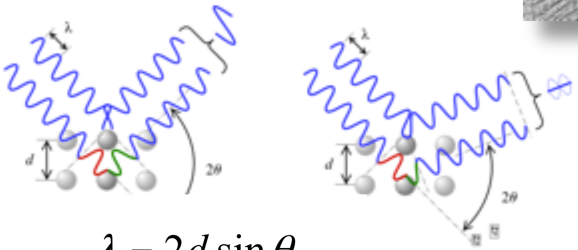


Cliff Shull

- Diffractometers - Measure structures
  - Where atoms and molecules are

→ To analyze the structure of a material from the scattering pattern produced when a beam of radiation or interacts with it

1 - 10 Ångström



$$\lambda = 2d \sin\theta$$

Braggs law

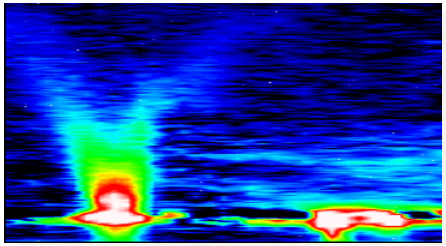
$$\varepsilon = -\cot(\theta)\,(\theta - \theta_0)$$

Bert Brockhouse

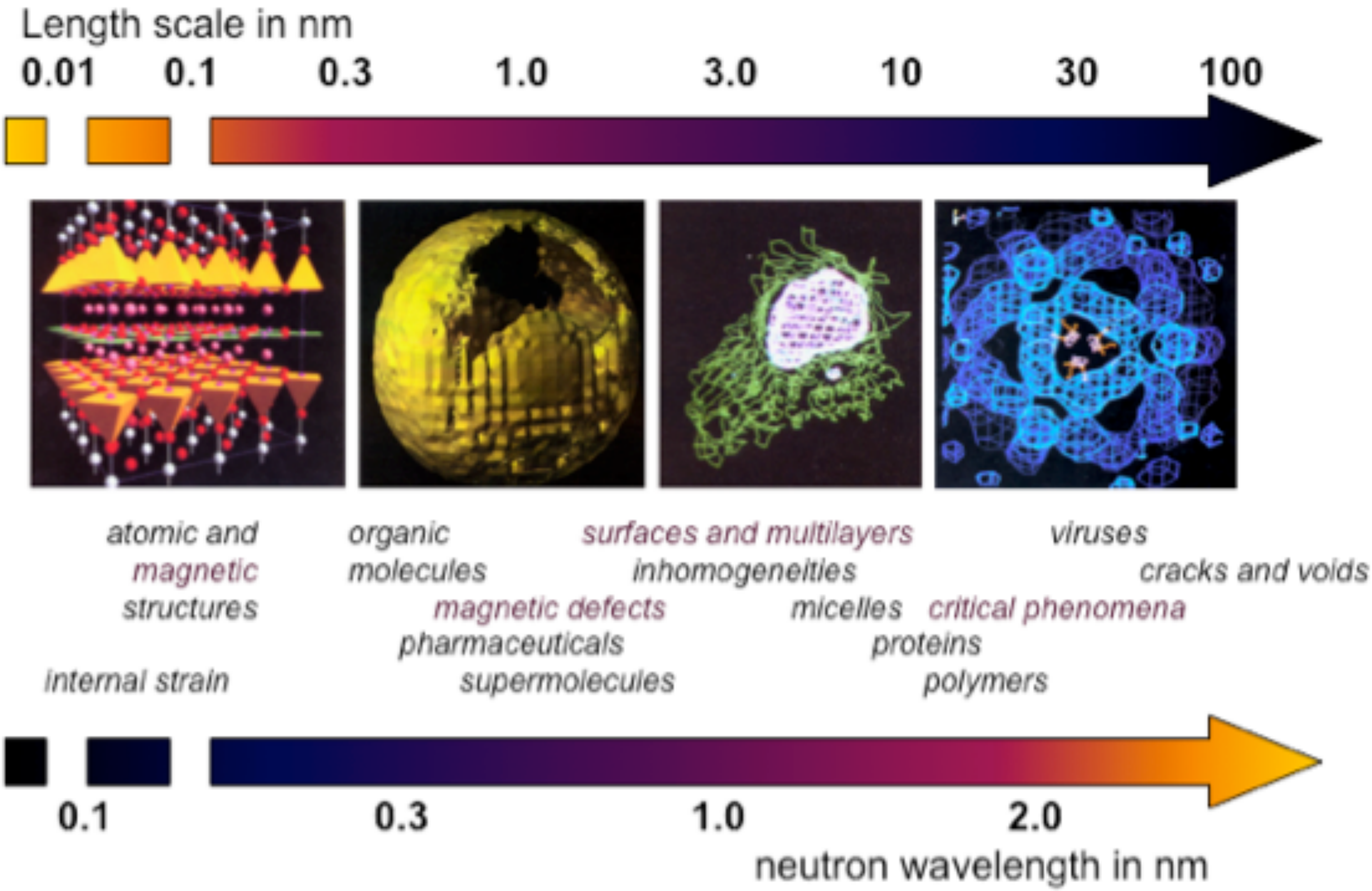
- Spectrometers - Measure dynamics
  - What atoms and molecules do

→ To measure properties of light over a specific portion of the electromagnetic spectrum

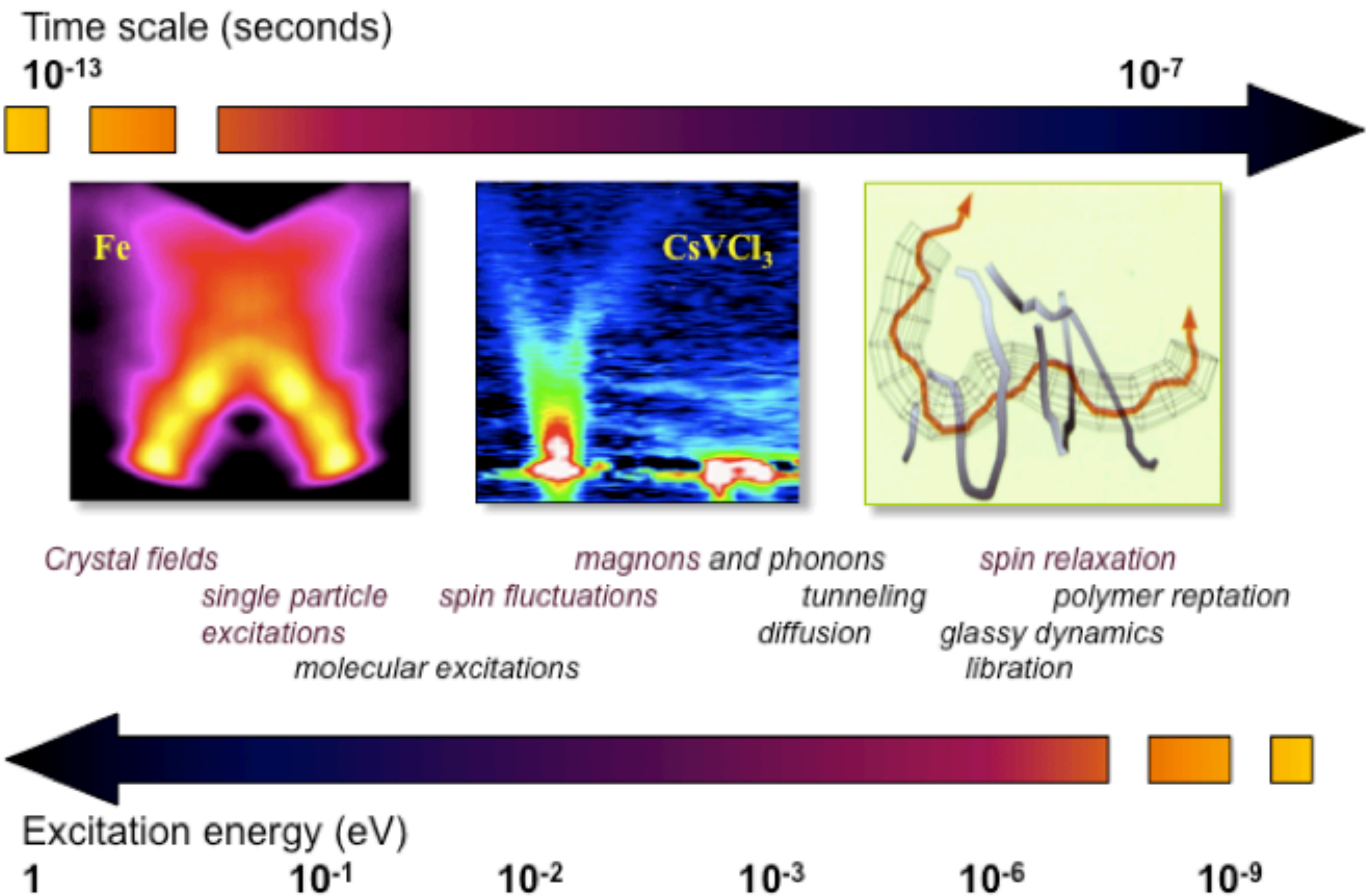
1 - 80 meV



Neutron Microscope – Length scales



Neutron Microscope – Time & energy scales



Example : Experimental Setup

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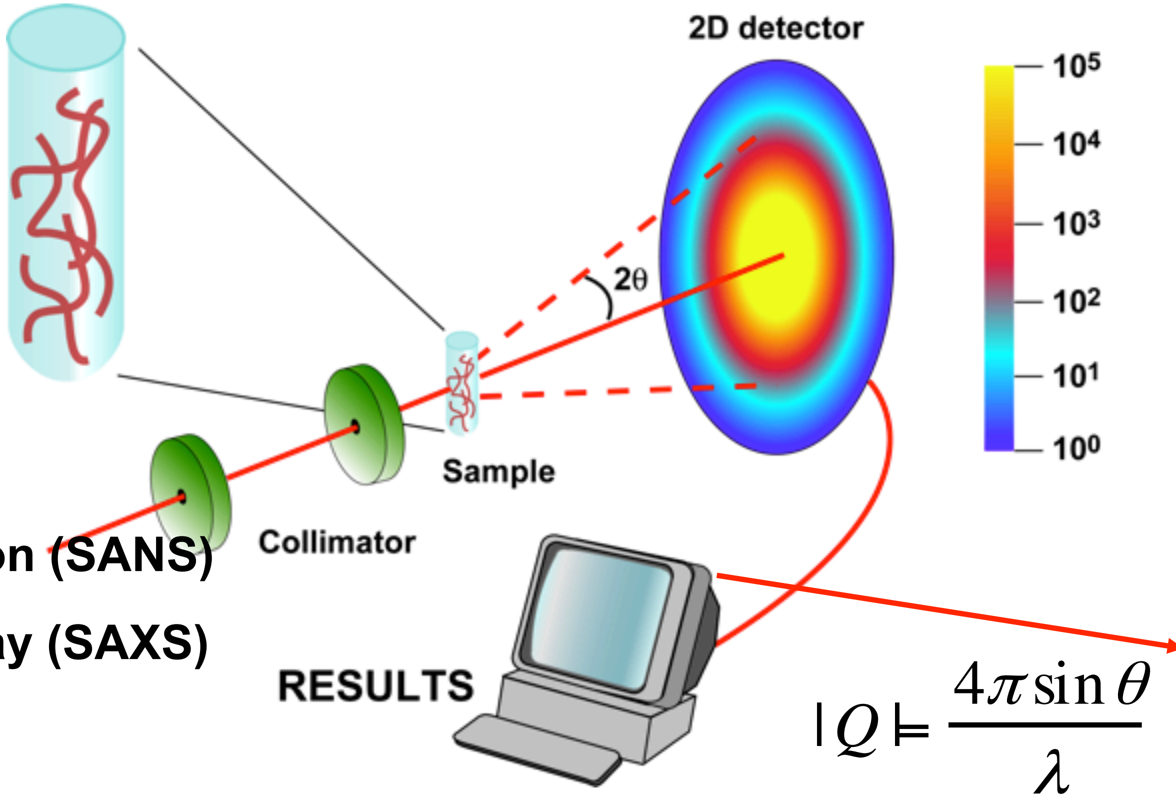
Beam:

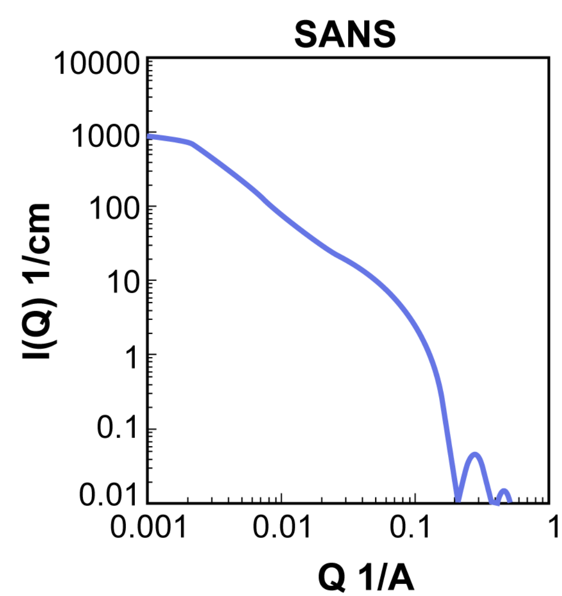
Neutron (SANS)

or X-ray (SAXS)



$$|Q| = \frac{4\pi \sin\theta}{\lambda}$$

Measures structures at length scales from 1 nm to 100 nm



De Broglie

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{ht}{mL}$$

+

Bragg

$$\lambda = 2d\sin\theta$$

=

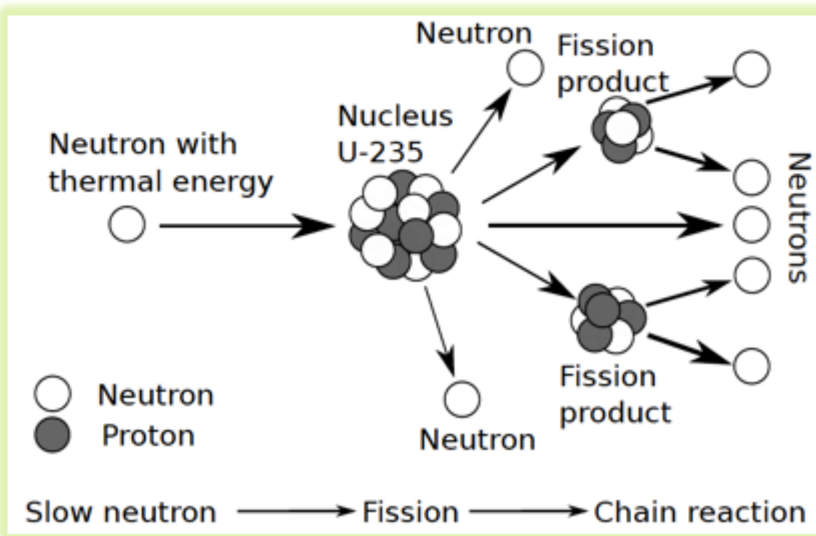
Time-of-Flight:

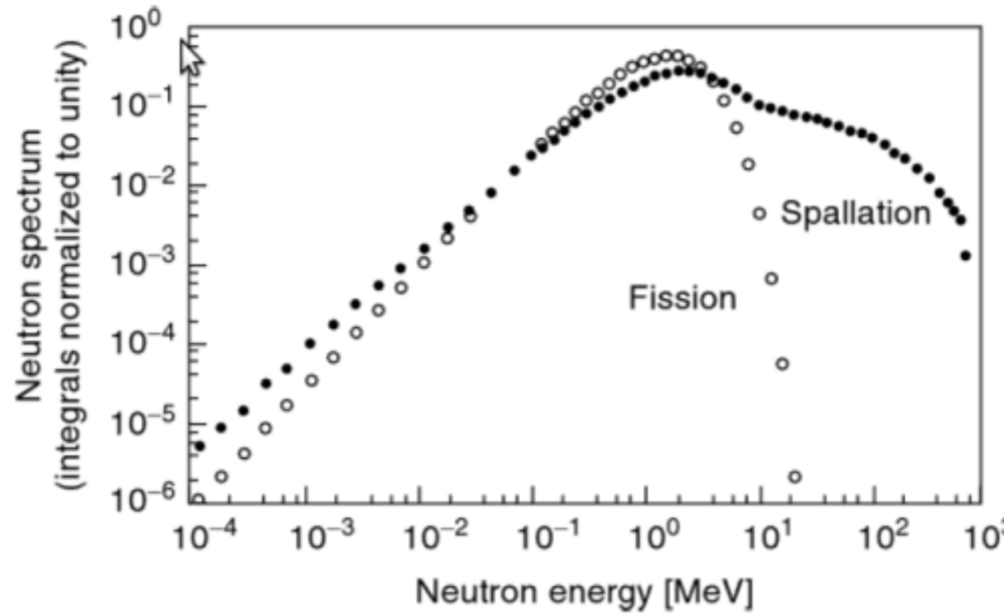
$$d = \frac{h}{2mL\sin\theta}t$$

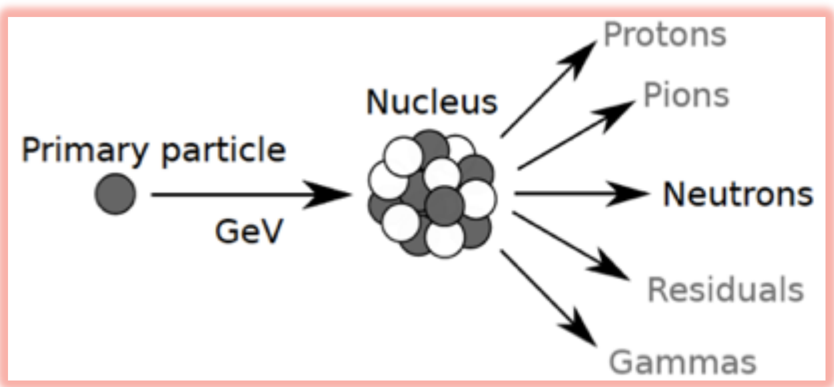
$Q_{min} \approx 0.03°$, $Q_{max} \approx 3°$

In a standard crystallography experiment, theta_max is typically 45 degrees

Fission and Spallation

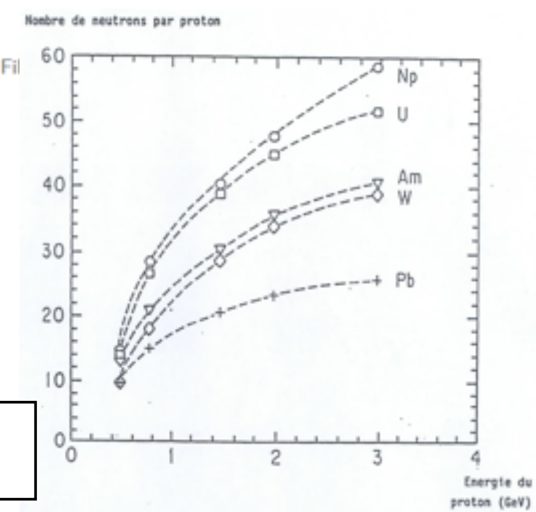






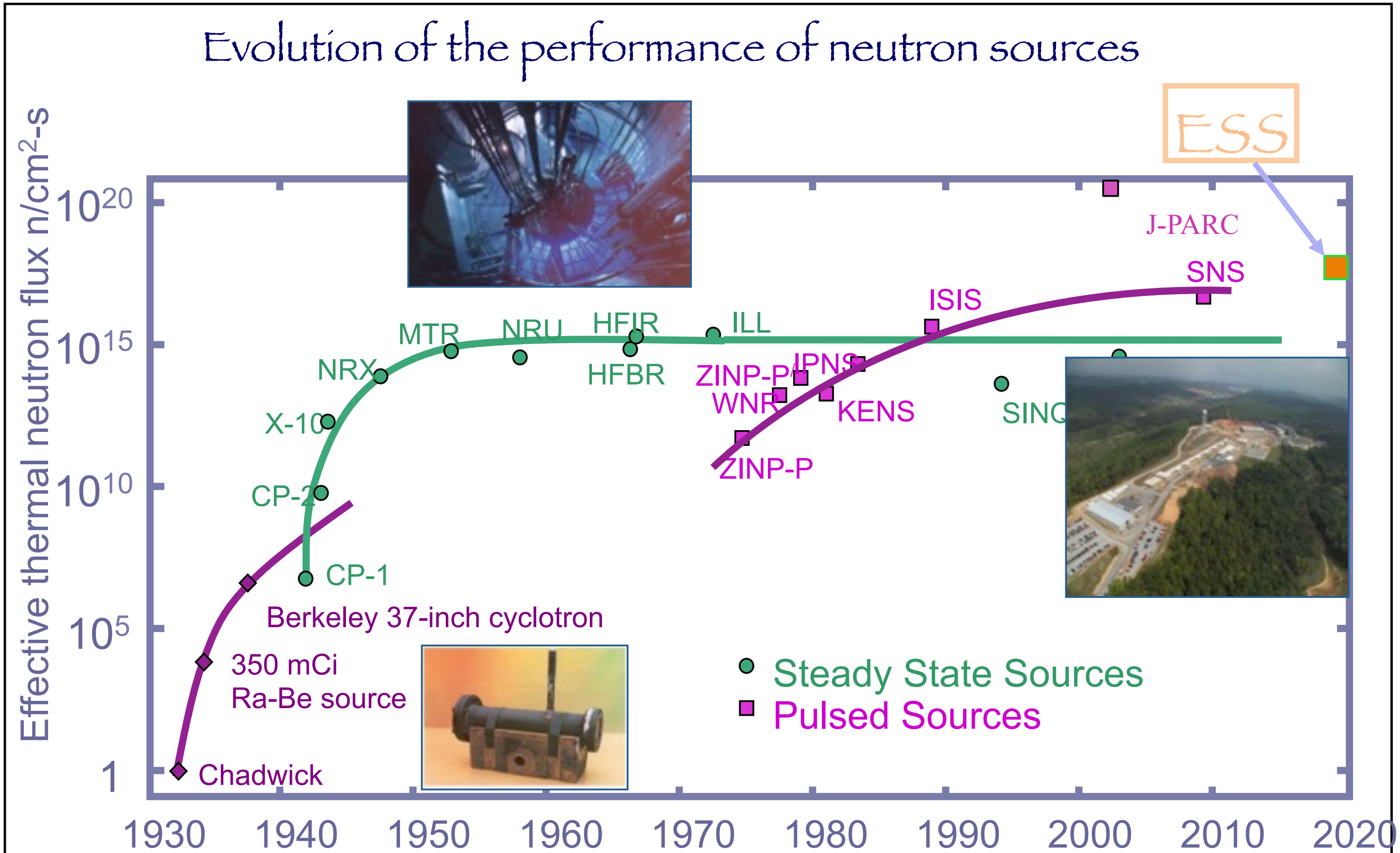
Spallation is a non-elastic nuclear interaction induced by a high-energy particle producing numerous secondary particles

[D. Fil



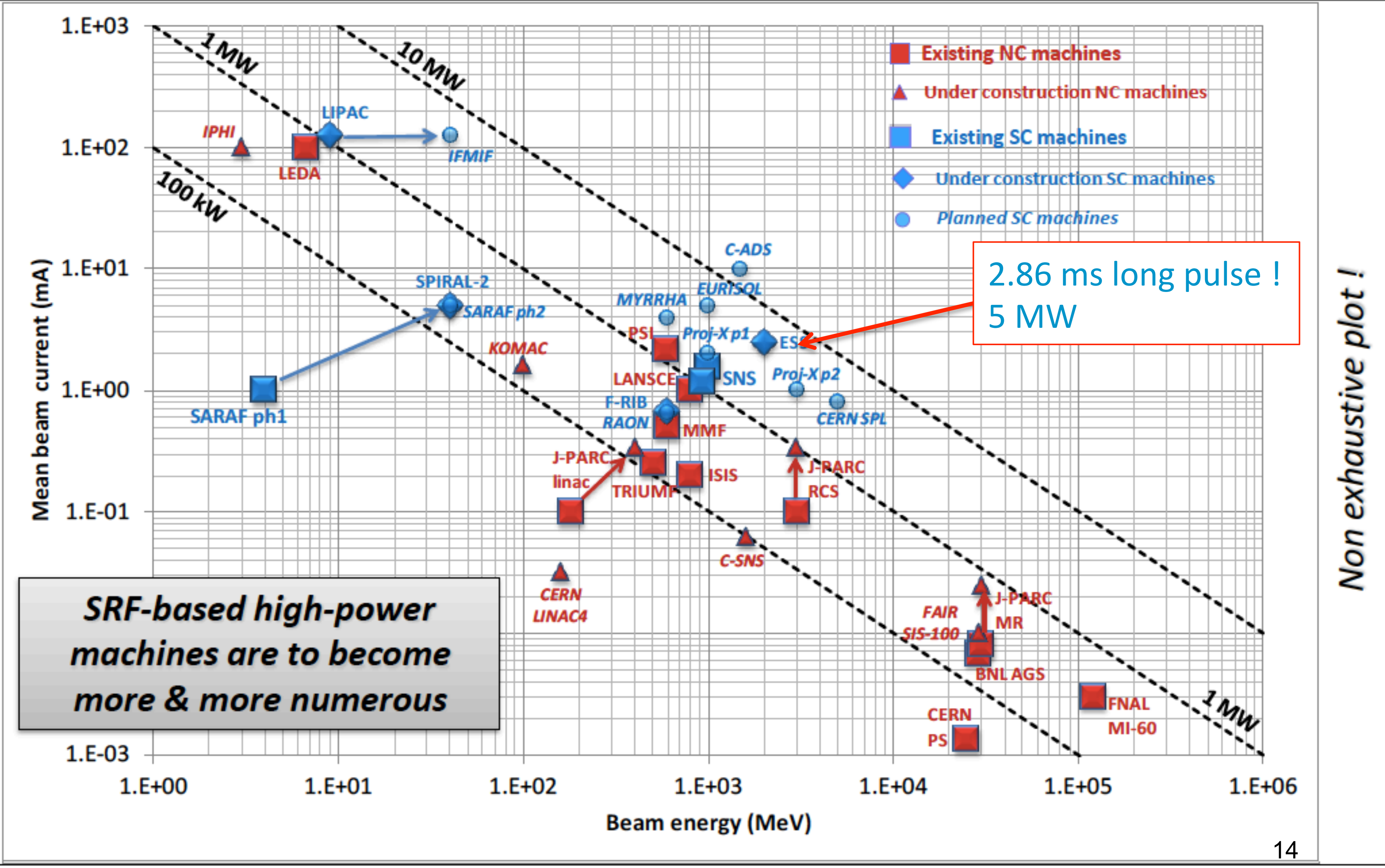
Y(E,A)=0.1 [A+20] [E (GeV) -0.12)] n/p

High time average and peak flux



(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

High power H/D beams around the world



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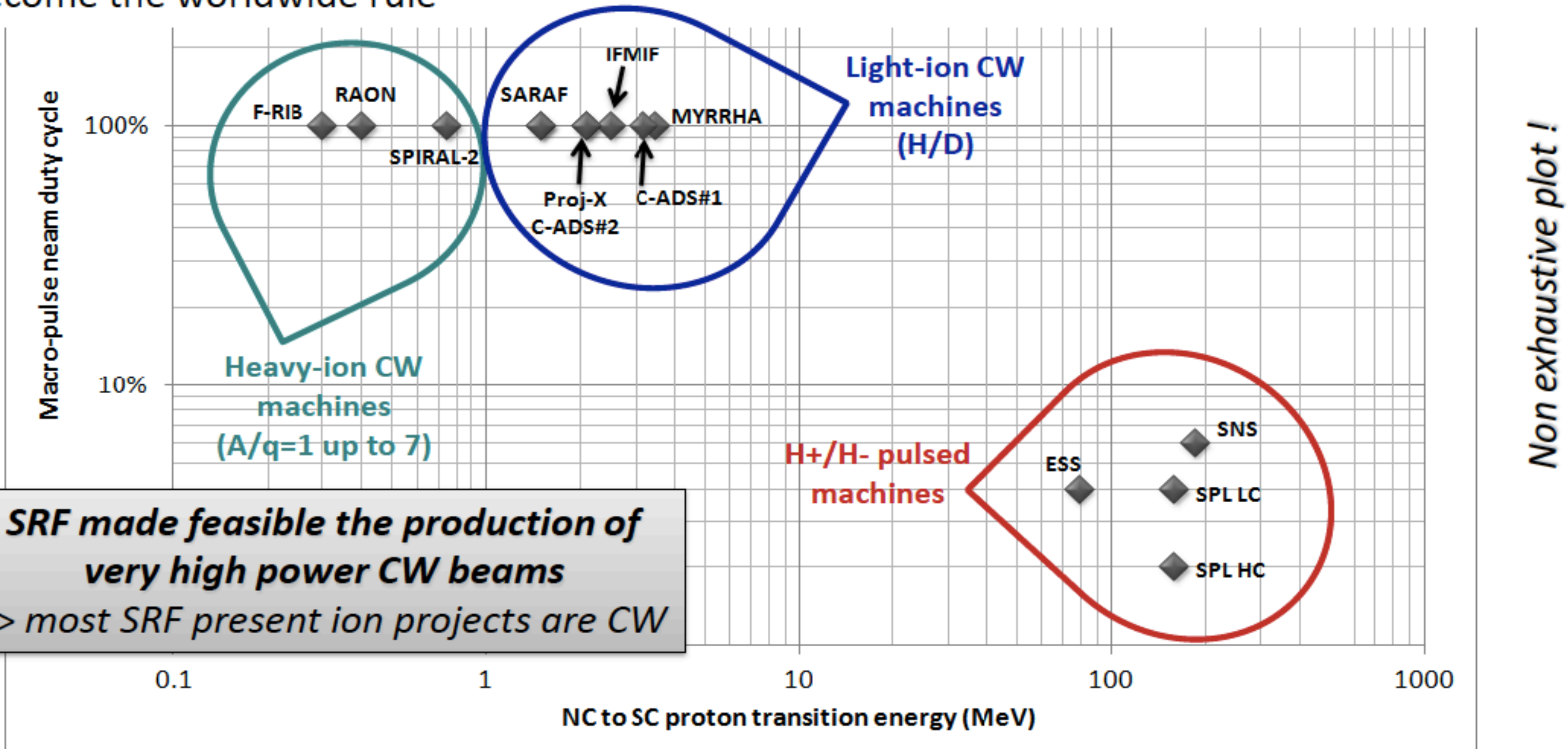
High power SRF linacs: NC to SC transition

○ **NC/SC transition** ideally minimizes overall power consumption ~ $DC^*(P_{cav}+P_{beam}) + P_{cryo}$

○ **For CW operation**, “SRF As Low As Reasonable Achievable” (i.e. down to the RFQ) has become the worldwide rule

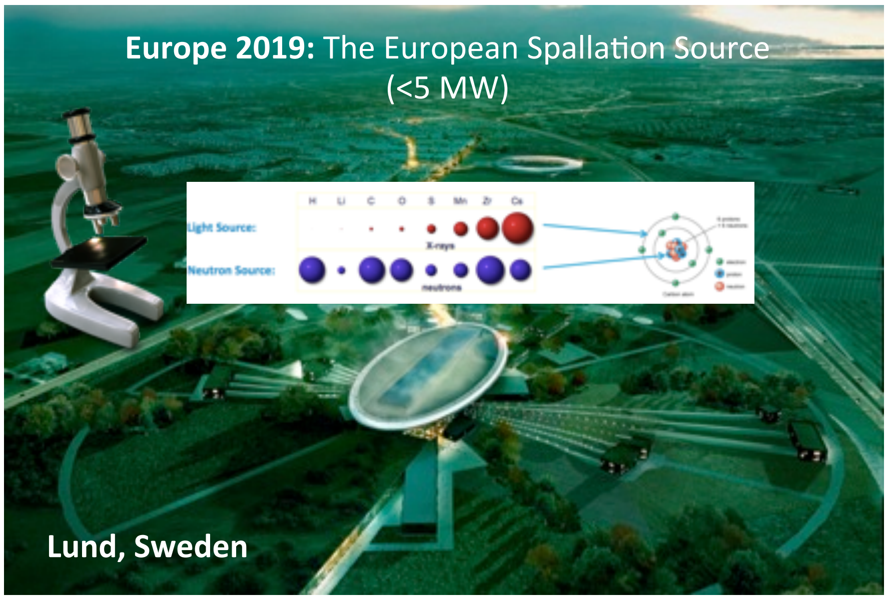


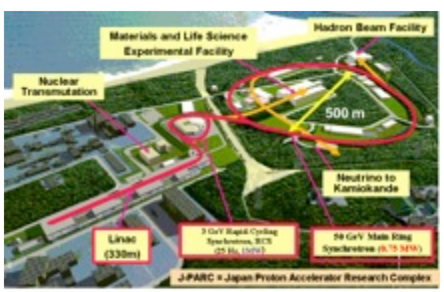
SRF made feasible the production of very high power CW beams
-> most SRF present ion projects are CW

European Spallation Source Project and Infrastructure

Spallation Sources

Philosophie de “Pré-vert”: Greenfield





Japan 2008:
JPARC (<1MW)

USA 2006:
SNS (<1.4 MW)
1 GeV, 26 mA in linac, 627 ns long pulse, 60 Hz

Neutron scattering offers a complementary view of matter in comparison to other probes such as x-rays from synchrotron light sources, The scattering cross section of many elements can be much larger for neutrons than for photons.

- ESS will bring new insights to the grand challenges of science and innovation
- Collaborative project: more than 17 countries
- 2014: Start of construction phase of the world's most powerful linear proton accelerator
- 2019: Provide the world's most advanced tools for studying materials with neutrons

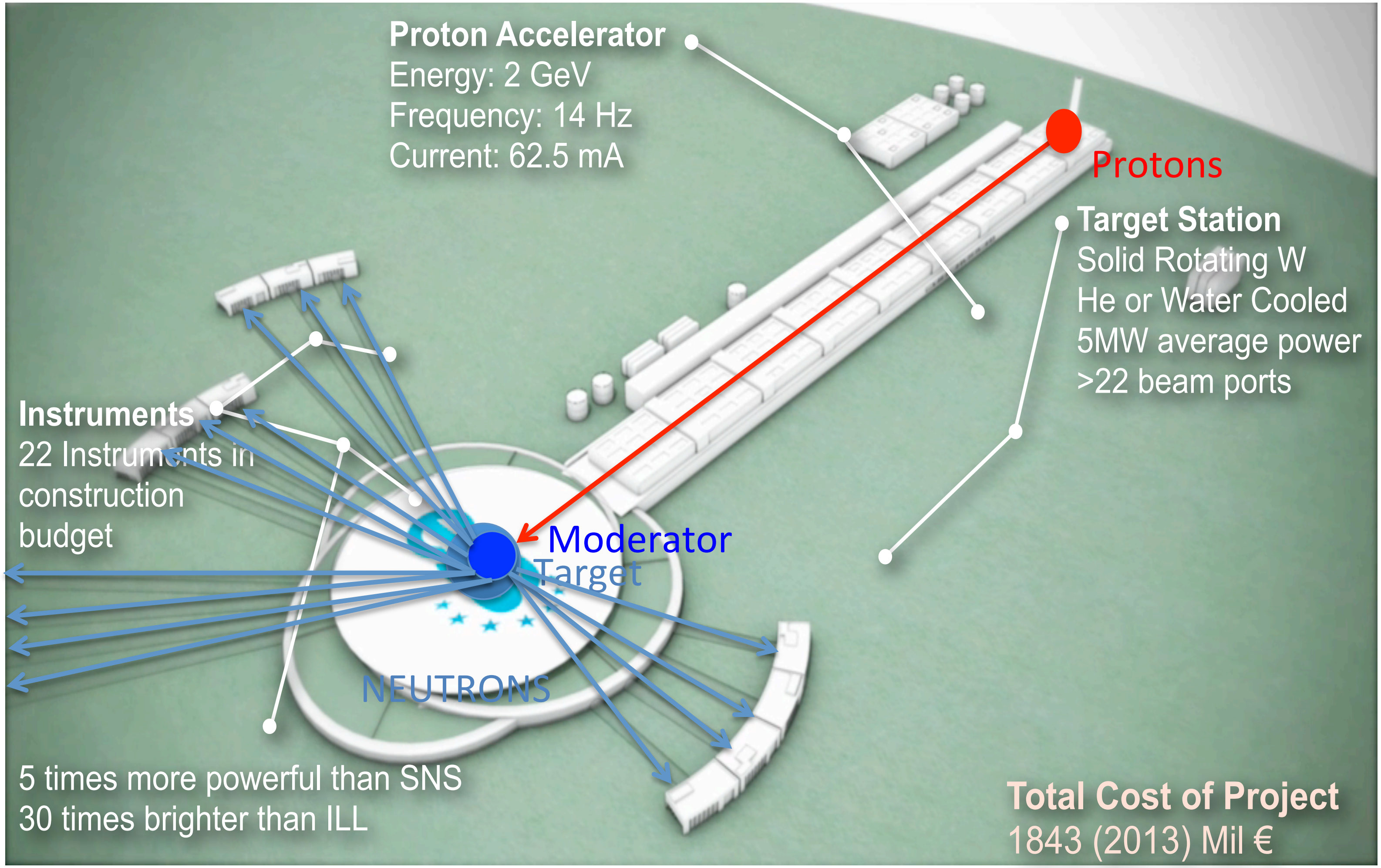
(~ 450 employees; > 2500 users / year)

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

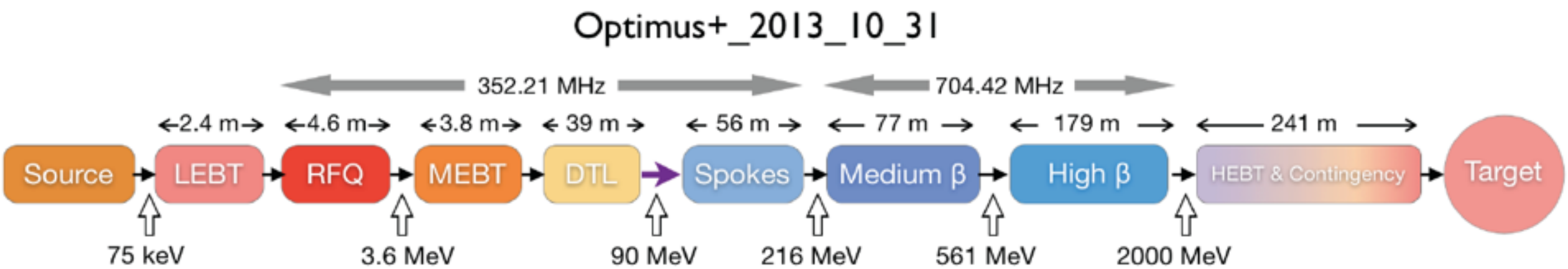
Jan Björklund (Swedish Research minister), Sofie Carsten Nielsen (Danish Research minister)
2014 September 2

2003
First European design effort of ESS completed
2009
Decision: ESS will be built in Lund
2012
ESS Design Update phase complete
2014
Construction work starts on the site
2019
First neutrons on instruments
2023
ESS starts user program
2025
ESS construction complete

Helicopter view of ESS



Linac redesign to meet ESS cost objective



Design Drivers:

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

Beam power (MW)	5
Beam current (mA)	62.5
Linac energy (GeV)	2
Beam pulse length (ms)	2.86
Repetition rate (Hz)	14

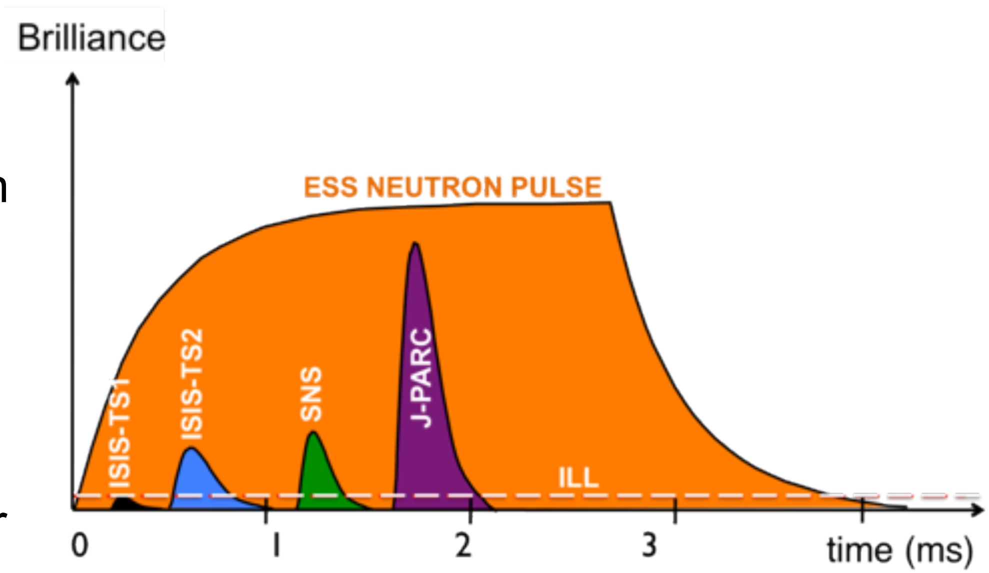
What is 5 MegaWatts?

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!!!

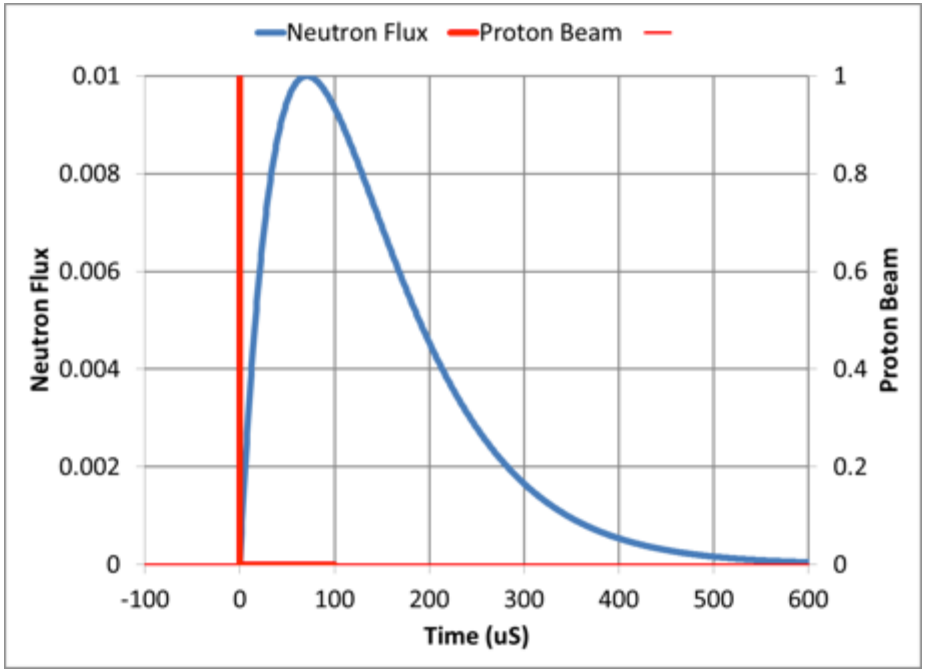
What is Different About ESS

- The average proton beam power will be 5 MW
  - Average neutron flux is proportional to average beam power
  - 5 MW is five times greater than SNS beam power
- The total proton energy per pulse will be 360 kJ
  - Beam brightness (neutrons per pulse) is proportional to total proton energy per pulse
  - 360 kJ is over 20 times greater than SNS total proton energy per pulse



Short Pulse Neutron Spallation Sources

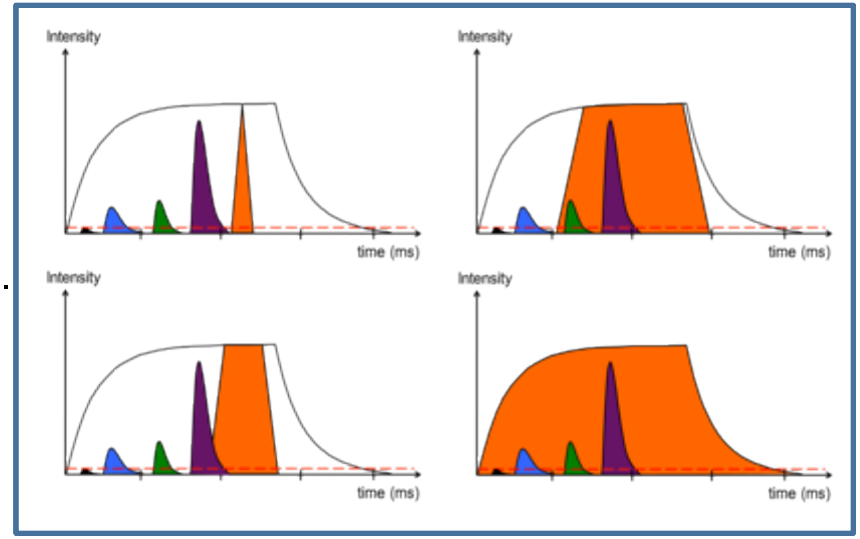
- The neutrons are cooled by a moderator downstream of the target.
- The time constant of the moderation process is about 100 μs.
- Proton beam pulses shorter than 100 μs serve only to stress the metal target and limit the beam power
  - Typical short pulse spallation sources have storage ring circumferences ~300 meters which produce 1 μs beam pulses
  - To build a storage ring with a 100 μs pulse would require a ring 30 km in circumference

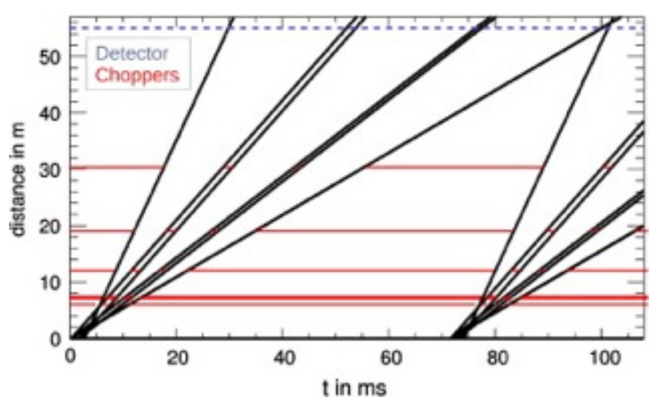


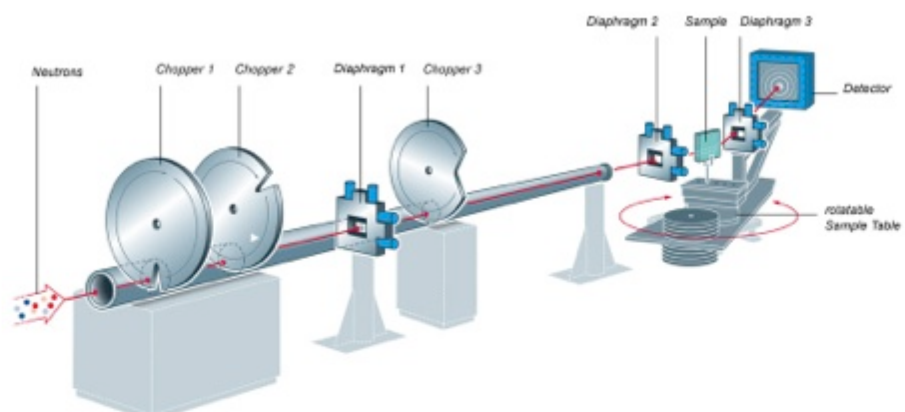
The target stress from the short beam pulse places a limit on proton beam power and ultimately neutron flux and brightness

Long Pulse Concept

- 360 kJ packed into a short pulse of 1 μs (360 GW peak) would destroy a target
- ESS will not use a compressor ring
  - The linac will send the beam directly to the target over a period of 3 ms at a rate of 14 Hz.
  - Peak beam power on the target is less than 125 MW
- The tradeoff is that ESS will
  - Have longer neutron guides between experiments and the target
  - Require a neutron choppers for precision energy measurements

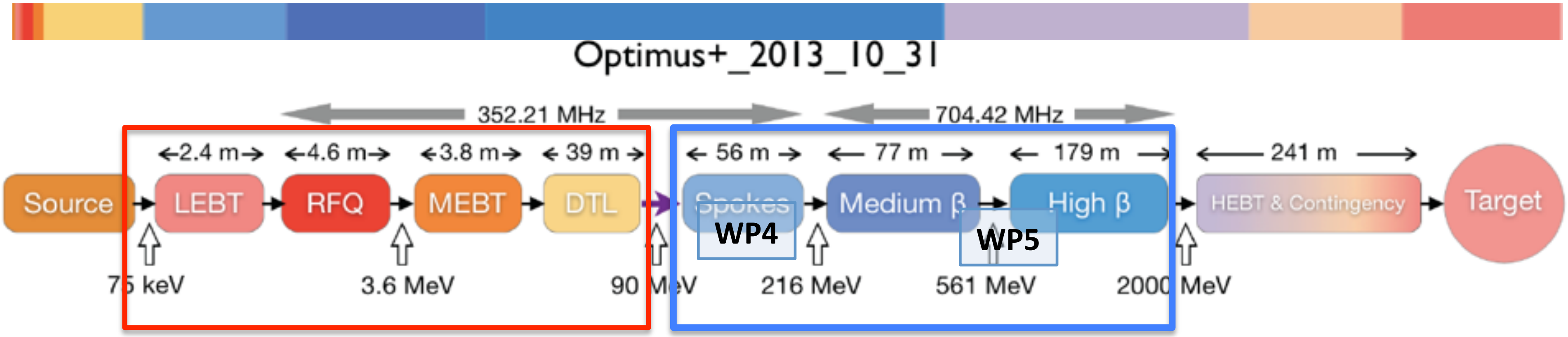




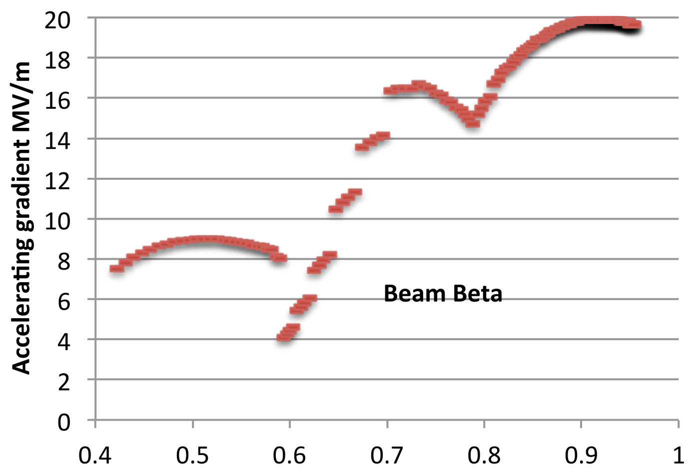


Few accelerator components

Linac redesign to meet ESS cost objective



	Num. of CMs	Num. of cavities
Spoke	13	26
Medium β (6-cell)	9	36
High β (5-cell)	21	84



[SRF2013 – "The ESS Superconducting Linear Accelerator", C. Darve, M. Eshraqi, M. Lindroos, D. McGinnis, S. Molloy, P. Bosland and S. Bousson]

Accelerator collaborations for ESS "start-up"

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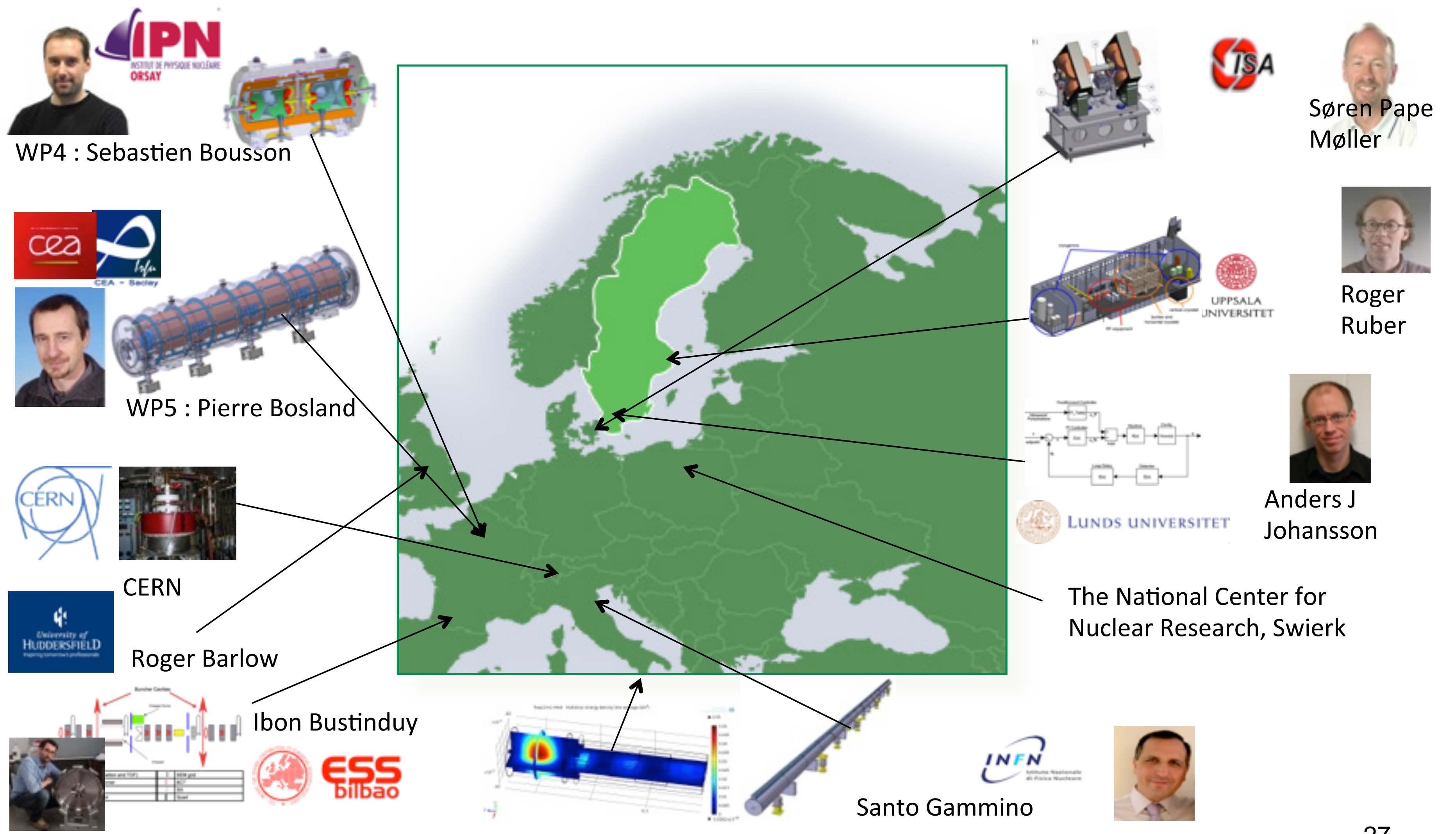
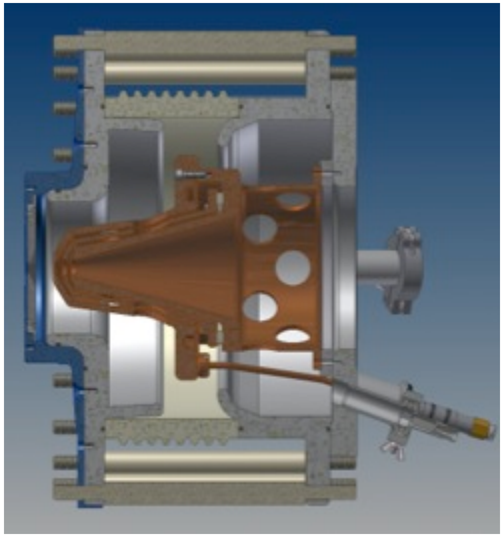


Front End Section

- Ion Source
  - Microwave Discharge Ion Source
  - Proton peak current ~75 mA
  - Total drain current ~100 mA
  - Output Energy 75 keV
  - Provided by INFN-LNS, Catania
  - Experience from TRIPS and VIS ion sources



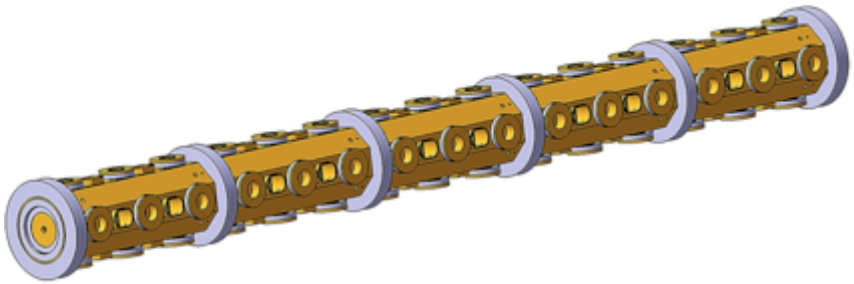
Extraction system of the ESS ion source (Courtesy L. Celona

- LEBT (Low Energy Beam Transport)
  - Dual solenoid layout
  - Functions:
    - Transport and match input the RFQ
    - Clean the beam pulse from the rise/fall time of the source with a slow chopper
    - Provide different level of beam current with an iris
  - Provided by INFN-LNS, Catania
  - Design close to the IFMIF LEBT

IFMIF source and LEBT at CEA-Saclay

Front End Section

- RFQ
  - 352 MHz 4-vanes RFQ
  - 5 segments of ~90 cm
  - Functions:
    - Accelerates
    - Bunches the pulse in a train of bunches
    - Focuses in the 3 planes
    - Provide different level of beam current with an iris
  - Foreseen transmission > 90 % for 70 mA input beam
  - Provided by CEA-Saclay

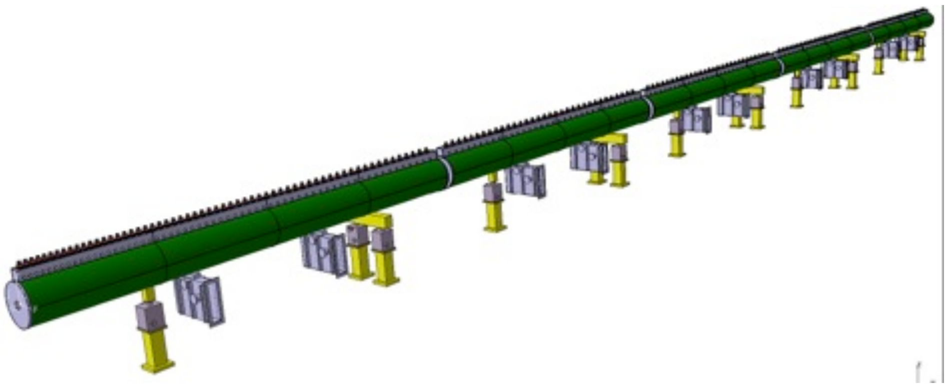


MEBT layout (Courtesy B. Cheymol)

- MEBT
  - Fully instrumented MEBT ~ 4.5 m
  - Functions:
    - Transport and match into the DTL
    - Characterize the beam
    - Fast chopping of the beam with rise/fall time ~ 10 ns
  - Provided by ESS-Bilbao

Front End Section

- DTL (Drift Tube Linac)
  - 352 MHz
  - 5 tanks
  - Length ~ 40 m
  - Output energy: ~90 MeV
  - Provided by INFN-LNL, Legnaro



DTL 3D view (Courtesy P. Mereu)

- Six klystrons
  - 352 MHz
  - with a maximum saturated power of 2.8 MW
  - and a duty factor of 4% are required for the Front End

ESS SRF Cavity Cryomodules

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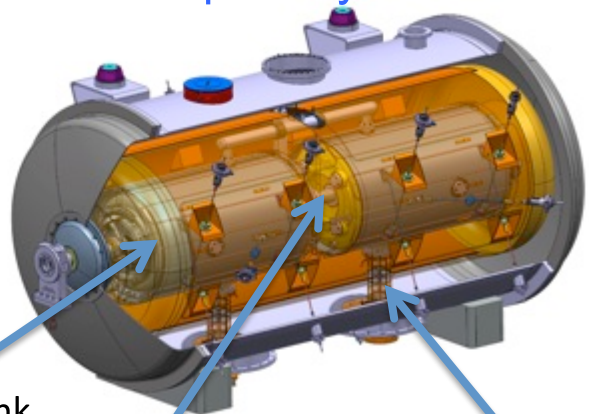
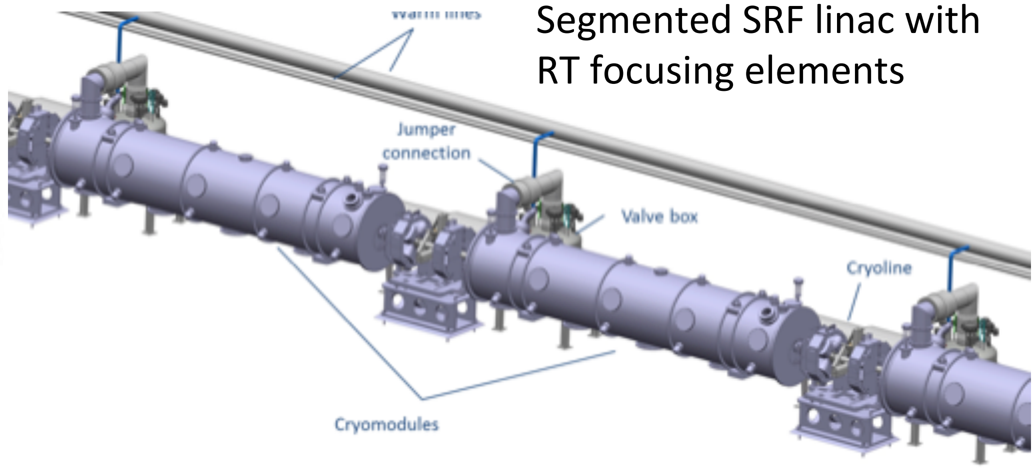
2 Spoke Cavities per Cryomodule





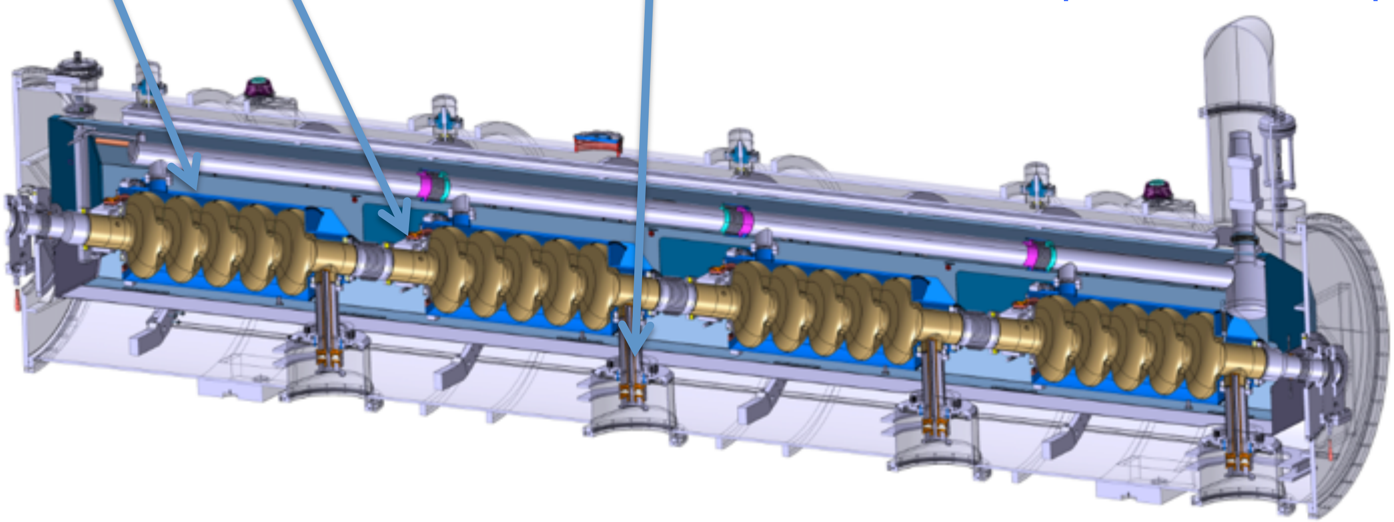
Segmented SRF linac with RT focusing elements

Ti. Helium tank

Cold tuning System

Power coupler

4 Elliptical Cavities per Cryomodule



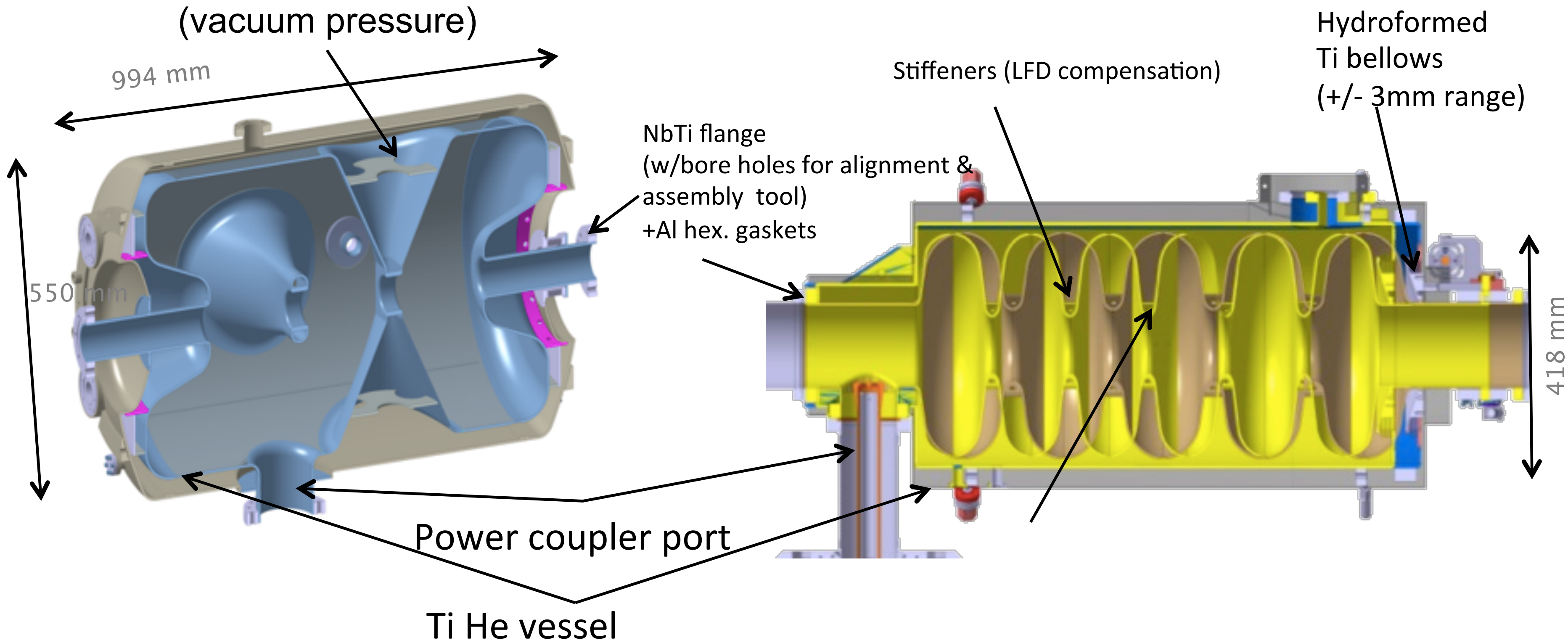
SRF Cavities Development

Spoke cavity

→ Stiffeners on the Spoke bars (vacuum pressure)

Elliptical cavities

→ No HOM power couplers



Medium beta:
- **6 cells – beta=0.67**
- **Length 1259,40mm**

High beta:
- **5 cells – beta=0.86**
- **Length 1316,91mm**

ESS Requirements and RF Parameters

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Spoke cavities

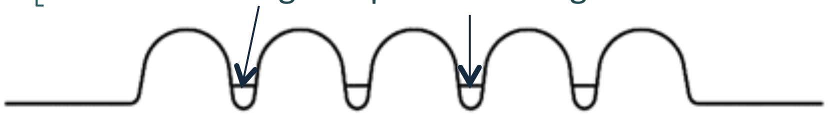
Frequency (MHz)	352,2
Optimum beta	0,50
Operating temperature (K)	2
Nominal Accelerating gradient (MV/m)	9
Lacc (βopt.x nb gaps x λ/2) (m)	0,639
Bpk (mT)	79 (max)
Epk (MV/m)	39 (max)
Bpk/Eacc (mT/MV/m)	<8,75
Epk/Eacc	<4,38
Beam tube diameter (mm)	50
RF peak power (kW)	335
G (Ω)	130
Max R/Q (W)	427
Qext	$2{,}85\ 10^{5}$
Q0 at nominal gardient	$1{,}5\ 10^{9}$

Elliptical cavities

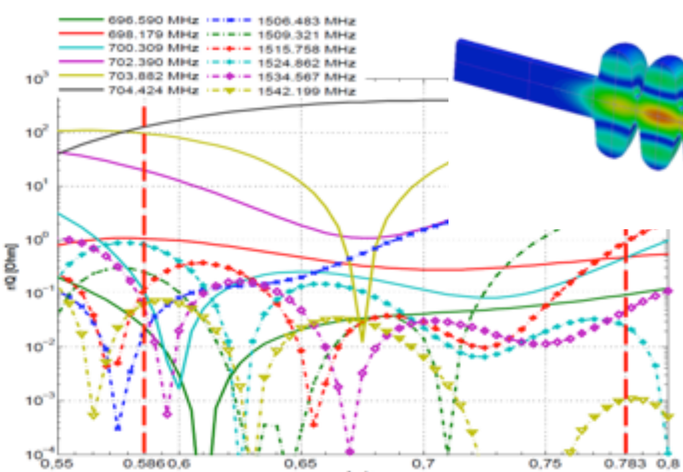
	Medium	High
Geometrical beta	0.67	0.86
Frequency (MHz)	704.42	
Number of cells	6	5
Operating temperature (K)	2	
Epk max (MV/m)	45	45
Nominal Accelerating gradient (MV/m)	16.7	19.9
Q_0 at nominal gradient	> 5e9	
Q_{ext}	$7.5\ 10^{5}$	$7.6\ 10^{5}$
Iris diameter (mm)	94	120
Cell to cell coupling k (%)	1.22	1.8
p,5p/6 (or 4p/5) mode sep. (MHz)	0.54	1.2
Epk/Eacc	2.36	2.2
Bpk/Eacc (mT/(MV/m))	4.79	4.3
Maximum. r/Q (W)	394	477
Optimum β	0.705	0.92
G (Ω)	196.63	241
RF peak power (kW)	1100	

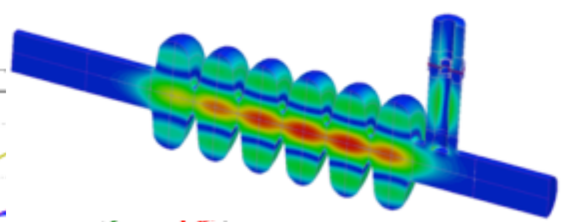
Elliptical Cavities

K_L reduction using compensation rings for medium and high-beta



Nominal wall thickness [mm]	3.6
Cavity stiffness Kcav [kN/mm]	2.59
Tuning sensitivity Df/Dz [kHz/mm]	197
K_L with fixed ends [Hz/(MV/m)²]	-0.36
K_L with free ends [Hz/(MV/m)²]	-8.9
Pressure sensitivity K_P [Hz/mbar] (fixed ends)	4.85



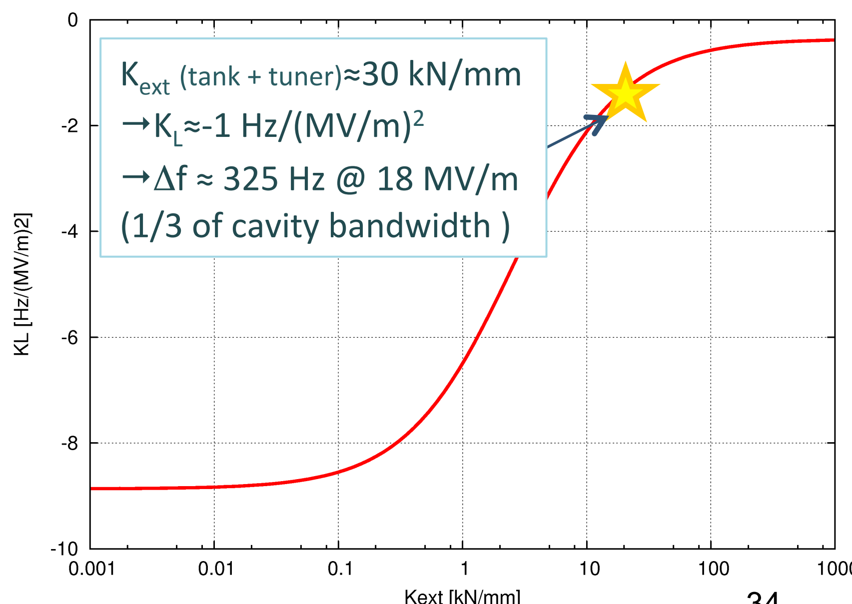


RF/mechanical design

Lorentz detuning

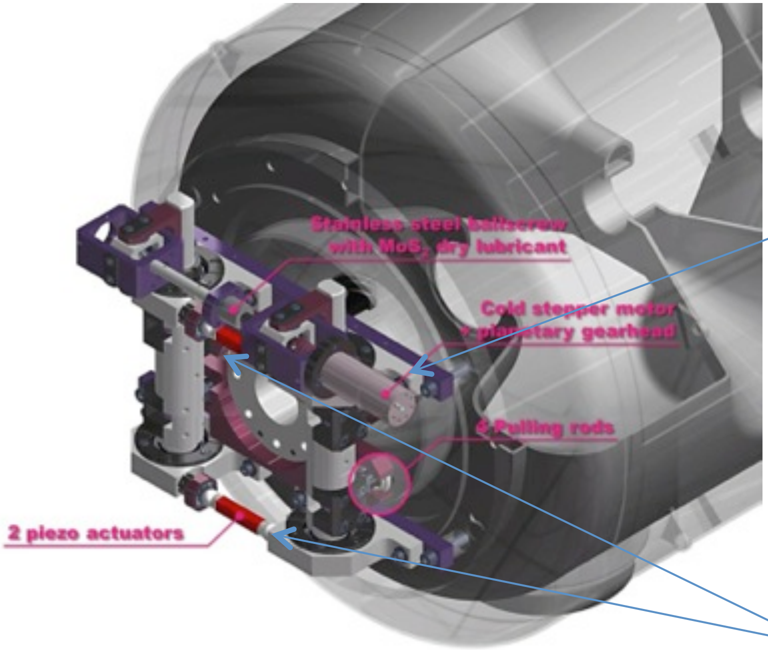
$$K_L = \Delta f / {E_{acc}}^2$$

$$K_L = K_{L\infty} + \frac{\Delta f}{\Delta z} \frac{\overrightarrow{F_\infty} . \overrightarrow{u_z} / {E_{acc}}^2}{K_{ext} + K_{cav}}$$



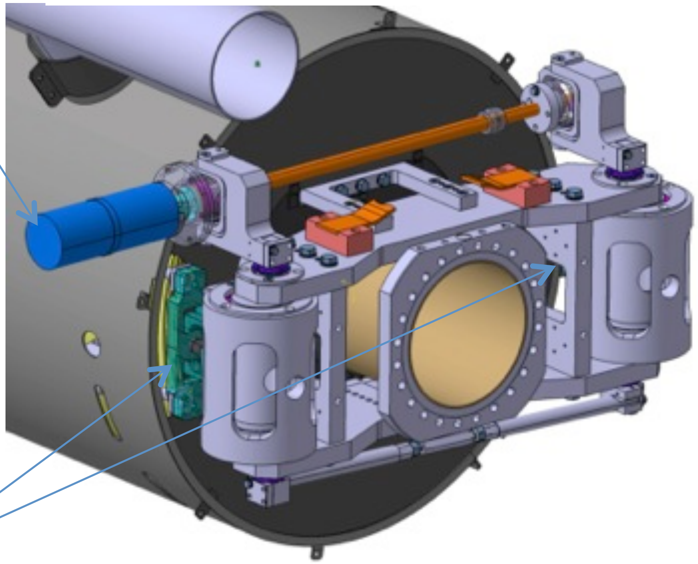
Cold Tuning System

Spoke CTS



Elliptical CTS

Type V ; 5-cell prototype
+/- 3 mm range on cavity



Stepper motor and planetary gearbox (1/100e) at cold and in vacuum

2 piezo stacks

Slow tuner

Main purpose : Compensation of large frequency shifts with a low speed

Actuator used : Stepper motor

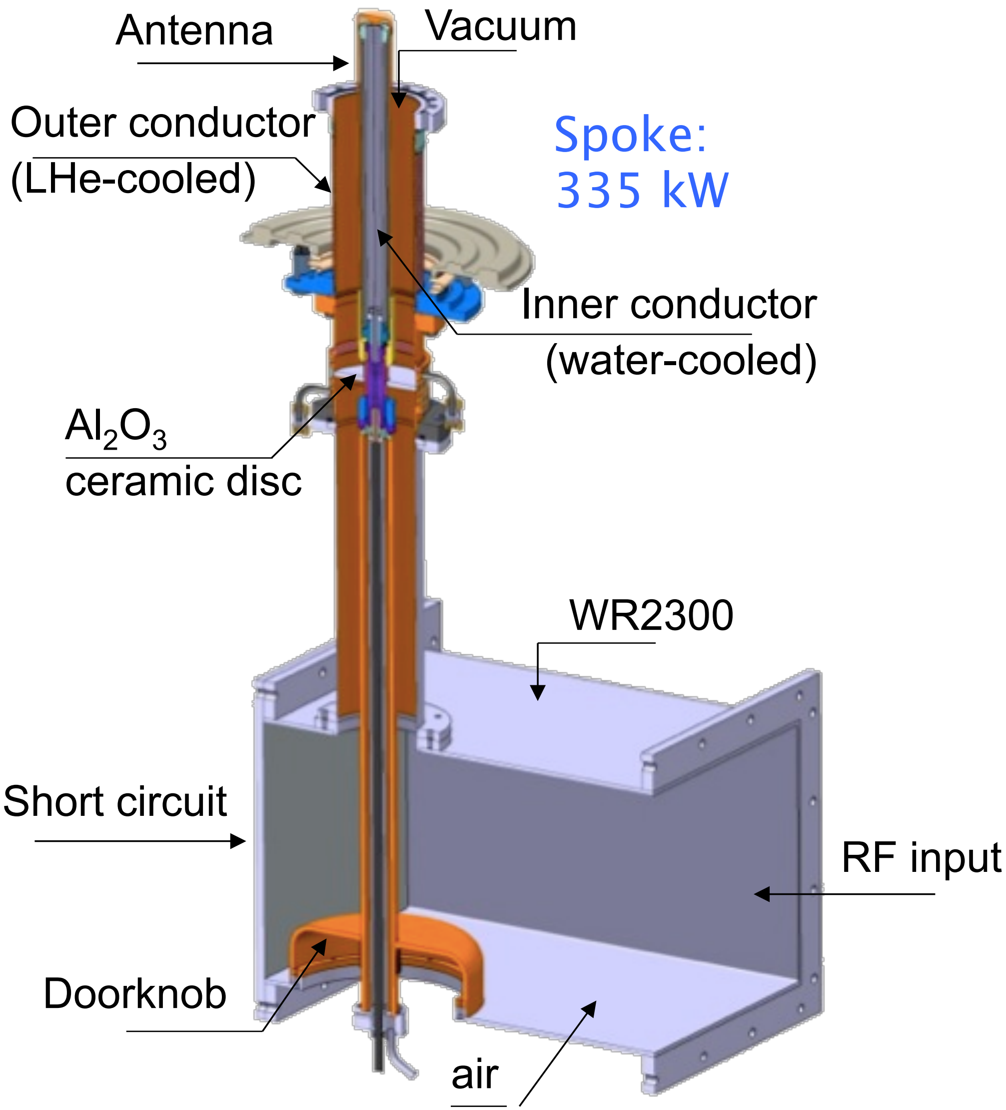
&

Fast tuner

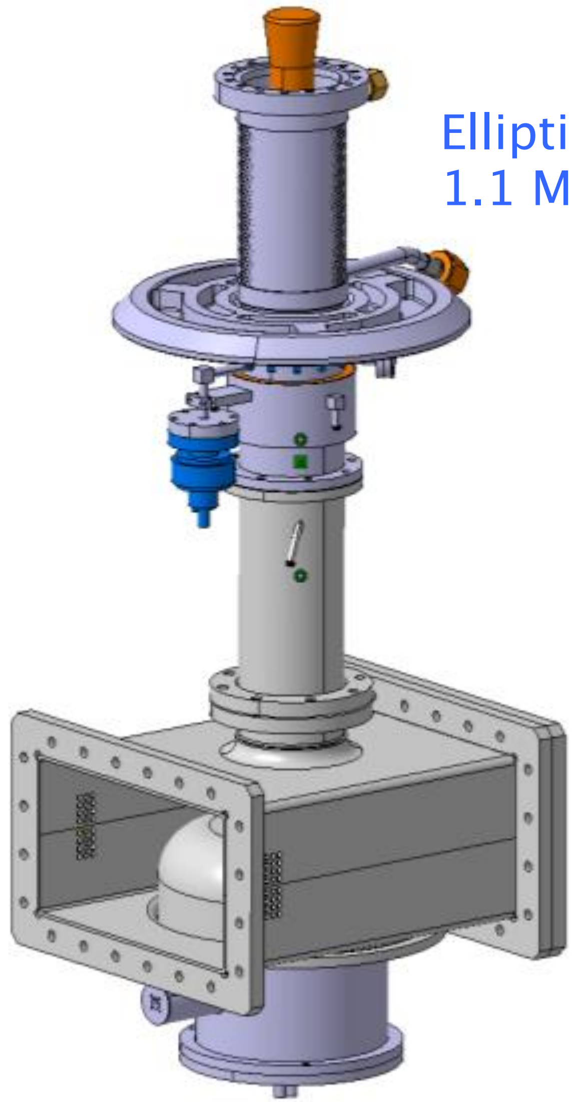
Main purpose : Compensation of small frequency shifts with a high speed

Actuator used : Piezoelectric actuators

Fundamental Power Coupler



Spoke:
335 kW

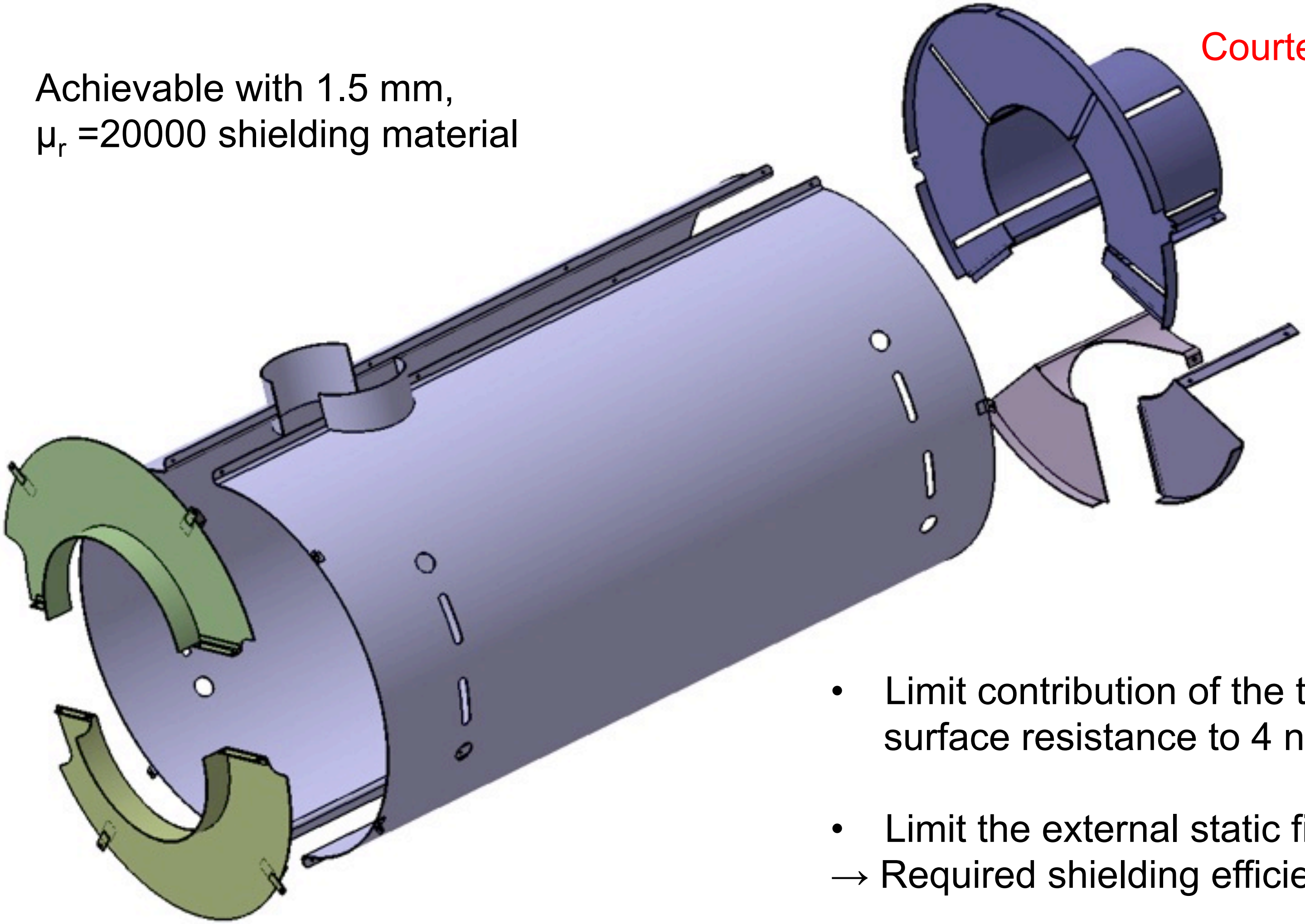


Elliptical:
1.1 MW

Magnetic shield, e.g. Elliptical cavity

Achievable with 1.5 mm,
μ_r =20000 shielding material

Courtesy of J. Plouin/ CEA



- Limit contribution of the trapped flux to the surface resistance to 4 nΩ

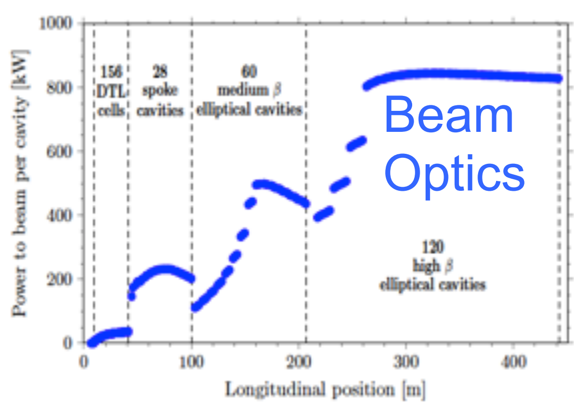
- Limit the external static field to Bext = 14 mG.

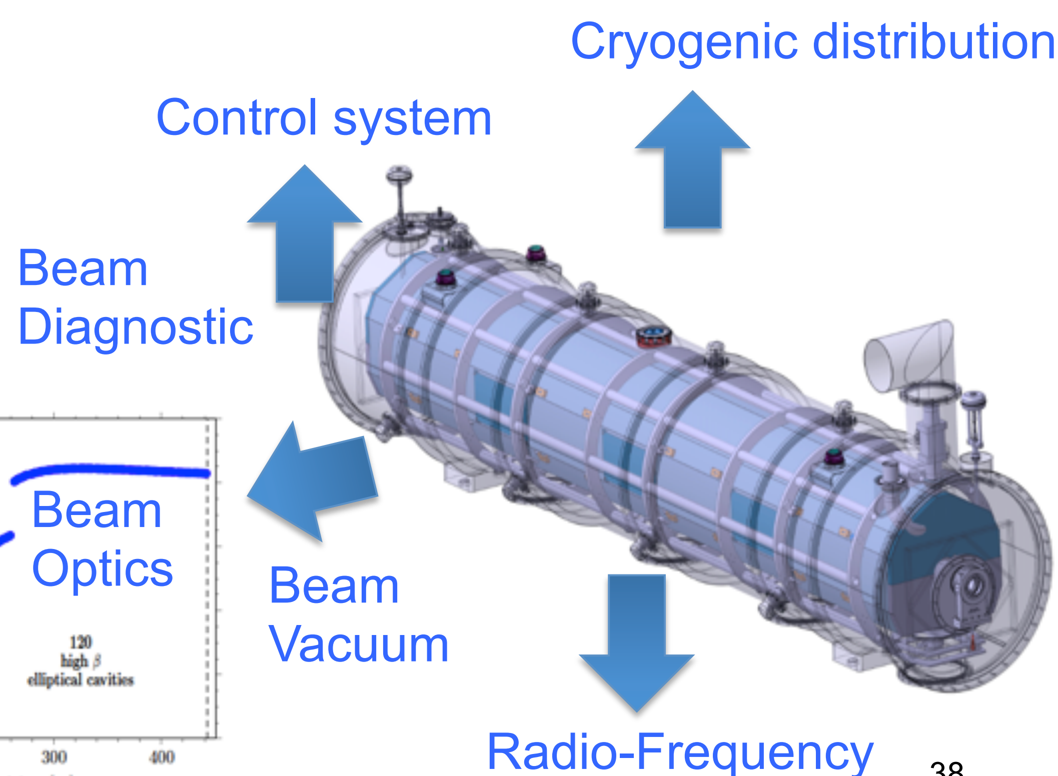
→ Required shielding efficiency equal to 35.

Cryomodule Interfaces

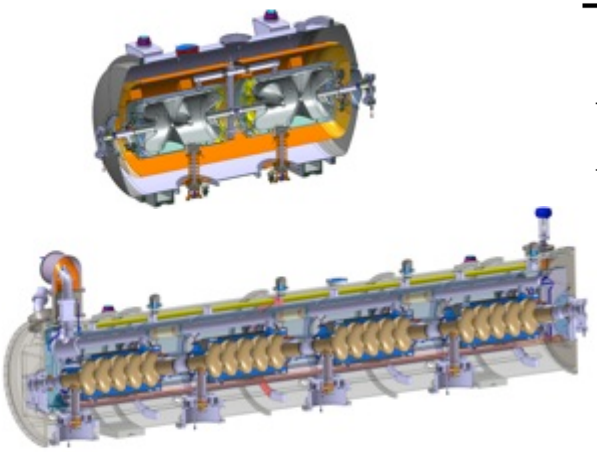
- Most AD internal Work Packages (beam optics, RF, cryo, vacuum, test stands, electrical, cooling, installation)
- External WPs cryomodule, cavity and designers and potential In-Kind collaborators
- Control command (Control Box, PLC, LLRF, MPS, EPICS)
- Data-logging ICS teams
- ESS ES&H
- Conventional Facility
- ESS system engineer, QA
- Survey experts
- Transport

Previous Linac version for comparison ➔





Cryomodule Heat Load Distribution



Per cryomodule

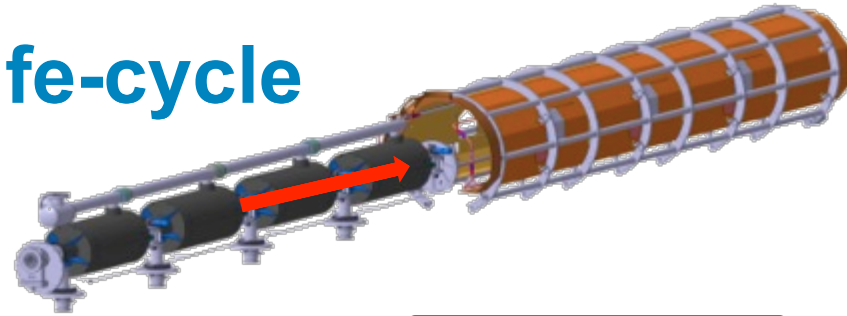
	Watts to 2 K							4.5 K Liquefaction (g/s)	Watts to ~50 K
	Static				Dynamic			Total	Total
	Others	Valves	Coupler	**Total**	Beam	Cavity	**Total**		
1 Spoke	3.3	0.2	3.5	**7**	1.5	5.0	**6.5**	0.092	30
1 MB	6.3	0.2	6.8	**13.3**	3.3	20	**23.3**	0.092	46.5
1 HB	6.3	0.2	6.8	**13.3**	3.3	24.4	**27.7**	0.092	46.5

Sum for the Linac cryoplant (incl. 14 extra HB for contingency space)

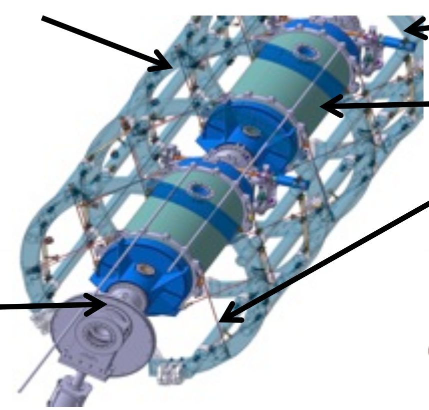
		Watts to 2K			4.5K Liquefaction (g/s)	Watts to ~ 50K
	Number of CMs	Static	Dynamic	Total	Total	Total
Spoke	13	91	84.5	175.5	1.196	390
Medium beta	9	119.7	209.7	329.4	0.828	418.5
High beta	35	472.5	627.9	1100.4	3.22	1627.5
Total	**57**	**683.2**	**922.1**	**1605.3**	**5.244**	**2436**

Heat load due to the beam losses deposit a maximum of 0.5 W/m to the Spoke, medium and high-beta cavities sections 2 K temperature levels.

Cryomodule life-cycle



- Cavity fabrication
- Chemical treatment
- High pressure rinsing In clean room (ISO5 or ISO4)
- Validation test of the cavity in vertical cryostat
- Qualified cavity storage
- Power coupler fabrication
- Assembling in clean room
- Coupler RF processing
- Processed couplers storage
- Cryomodule components fabrication
- Tools fabrication
- Cavity string assembling in clean room
- Cryomodule assembling
- Transport
- Cryomodule reception and storage
- Validation test of the cryomodule
- Cryomodule storage
- Cryomodule on beam line



Courtesy of Pierre Bosland CEA/IRFU

Elliptical Cavity Preparation

EUROPEAN SPALLATION SOURCE

High beta cavity fabrication (Zanon and RI)

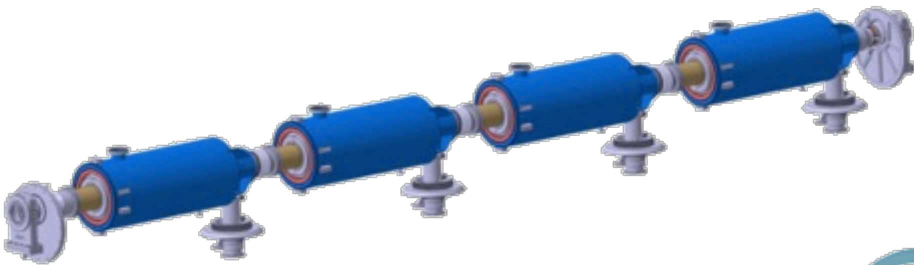
Vertical Electro-Polishing system@ CEA

Study of the tooling in progress @ CEA

Example of the tooling for the assembling of the coupler on the cavity in clean room

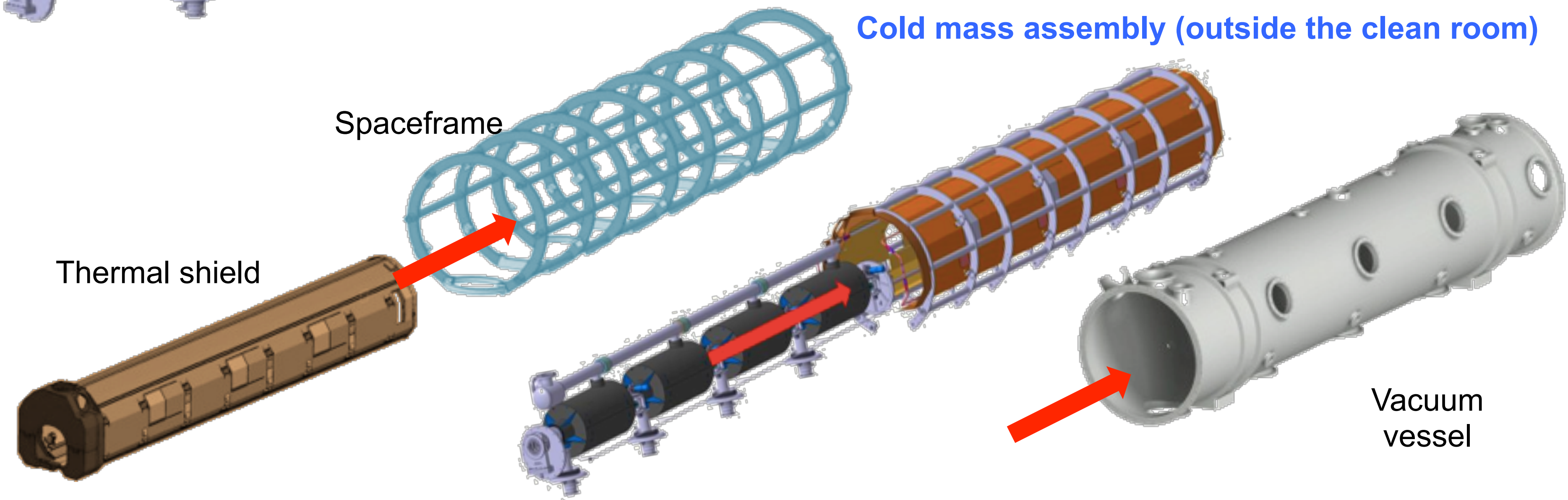
Elliptical Assembly Procedure

Cavity string assembly in clean room



Build on existing knowledge (SNS, XFEL)
- Develop Training and “Fabrication file”
- Pre-industrialization
- Industrialization

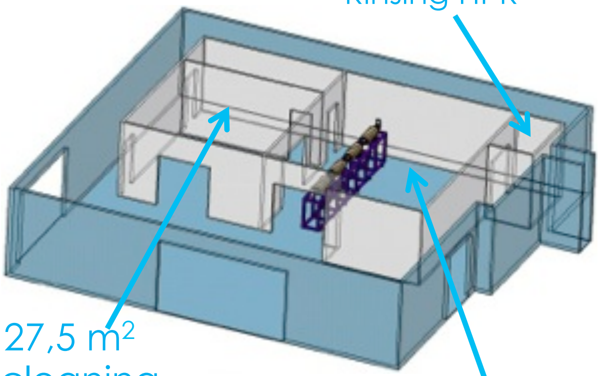
Cold mass assembly (outside the clean room)



Design concept of the tooling: most of parts will be used for both types of elliptical cryomodules

Infrastructure in Saclay

Clean room for the M-ECCTD
(and H-ECCTD)



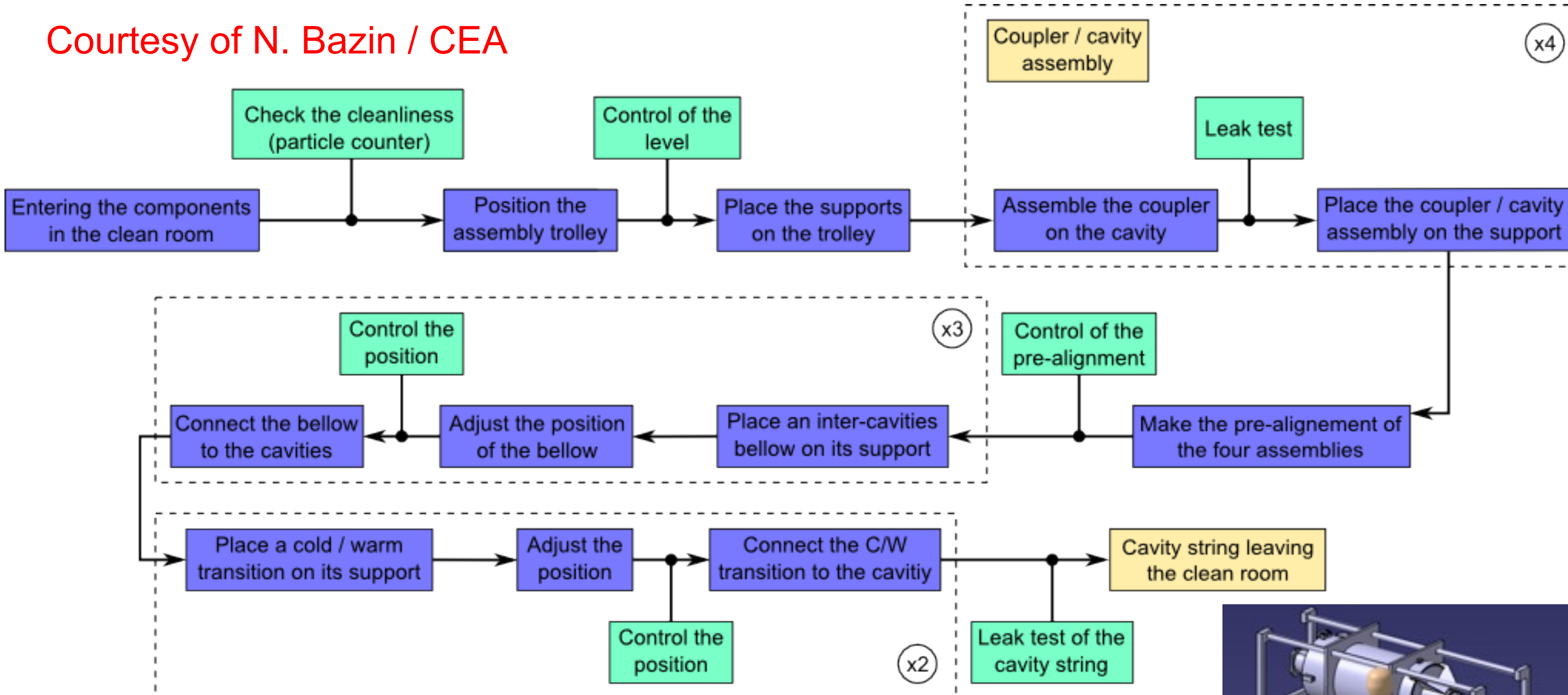
The clean room inauguration
→ May 13th 2014

Possible IKC for the assembly by industry at Saclay (XFEL cryomodules assembly)

- Uses the current infrastructure at Saclay
- Benefits from the experience of the XFEL cryomodule assembly (ALSYOM)

Assembly of elliptical cryomodules

Courtesy of N. Bazin / CEA



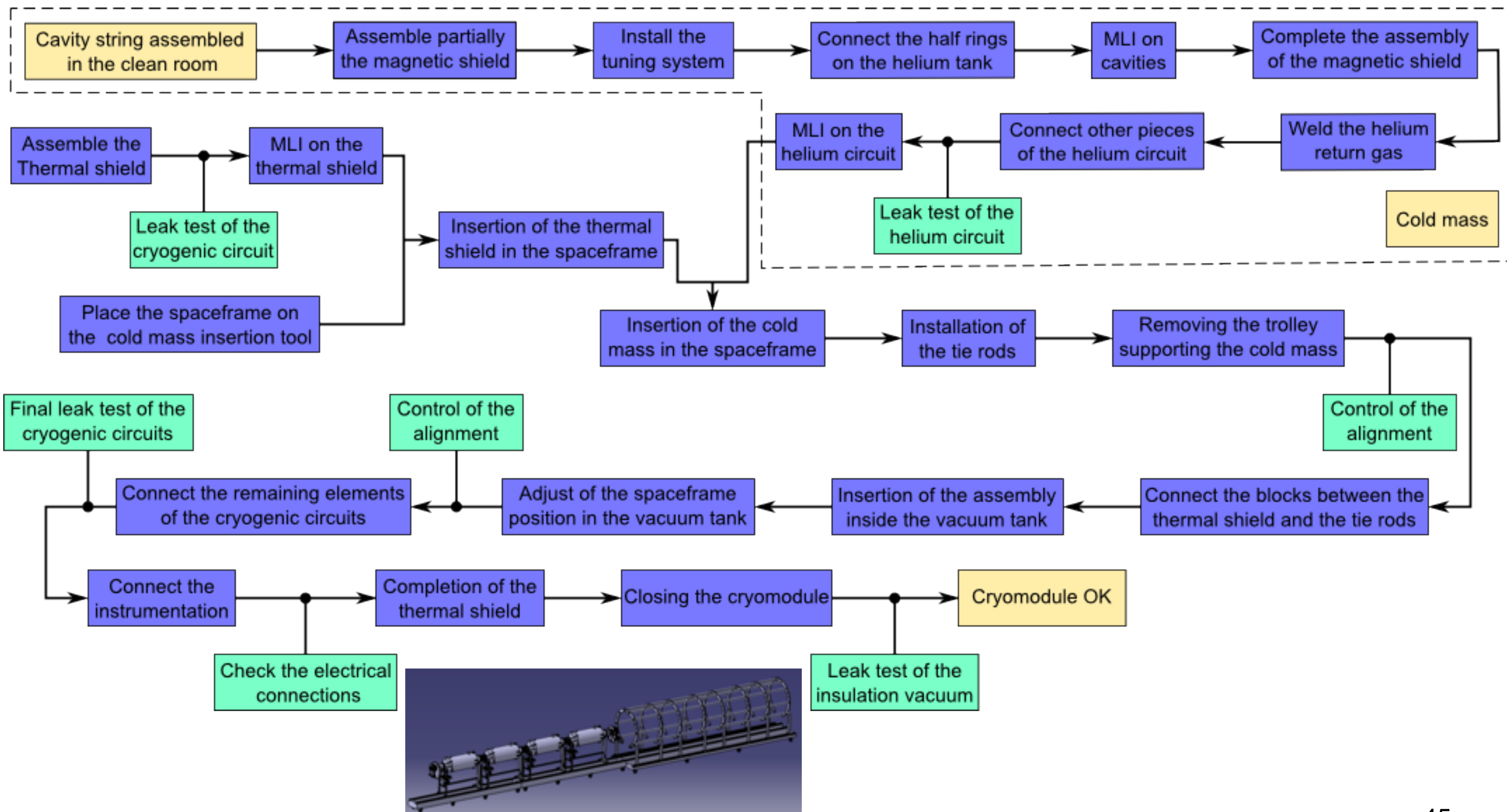
- ❑ Detailed procedures will be defined for every phases
    - Components and tools
    - Operations
    - Controls and tests

Tooling for elliptical cavities:

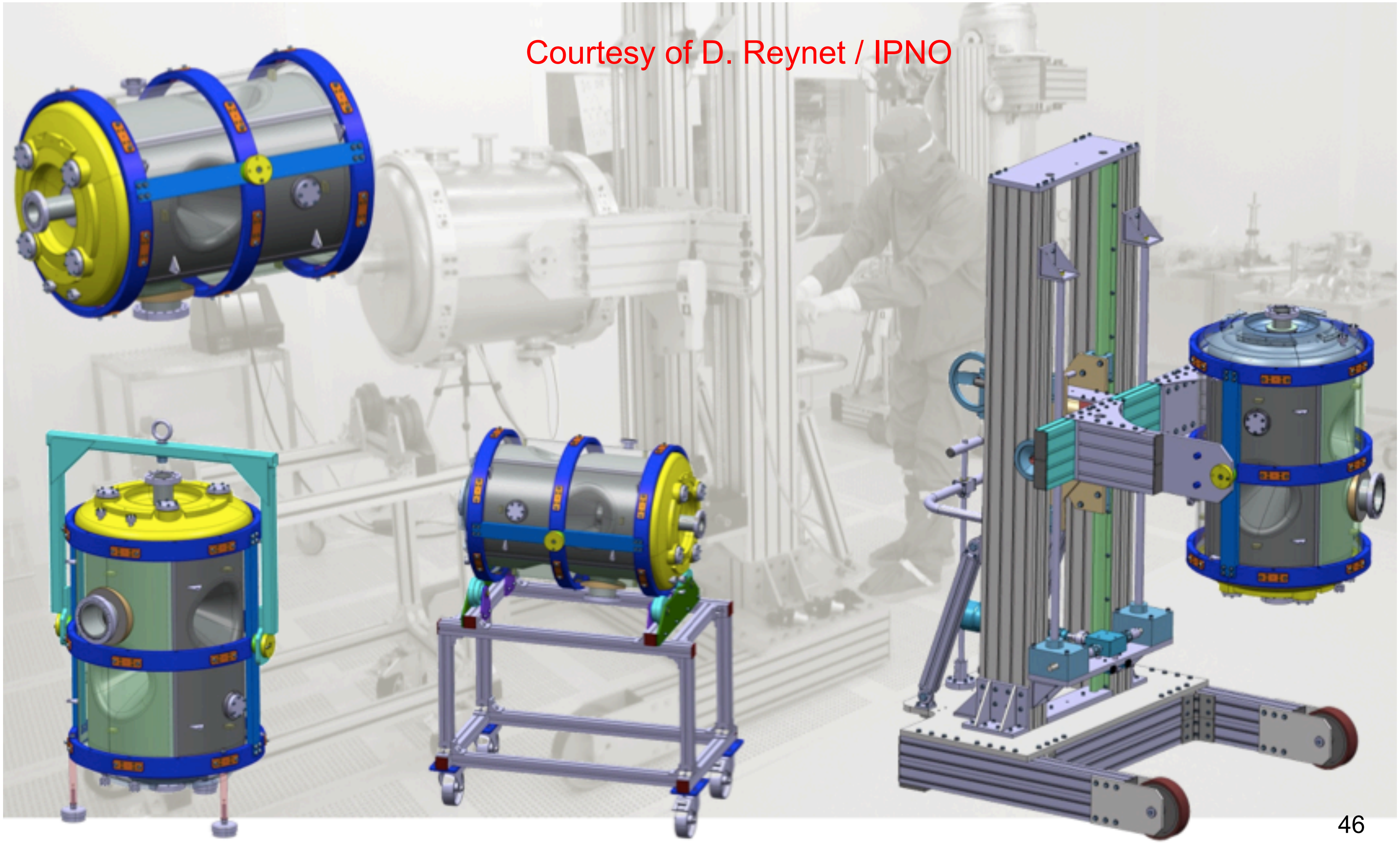
Assembly: outside clean room

EUROPEAN SPALLATION SOURCE

Courtesy of N. Bazin / CEA

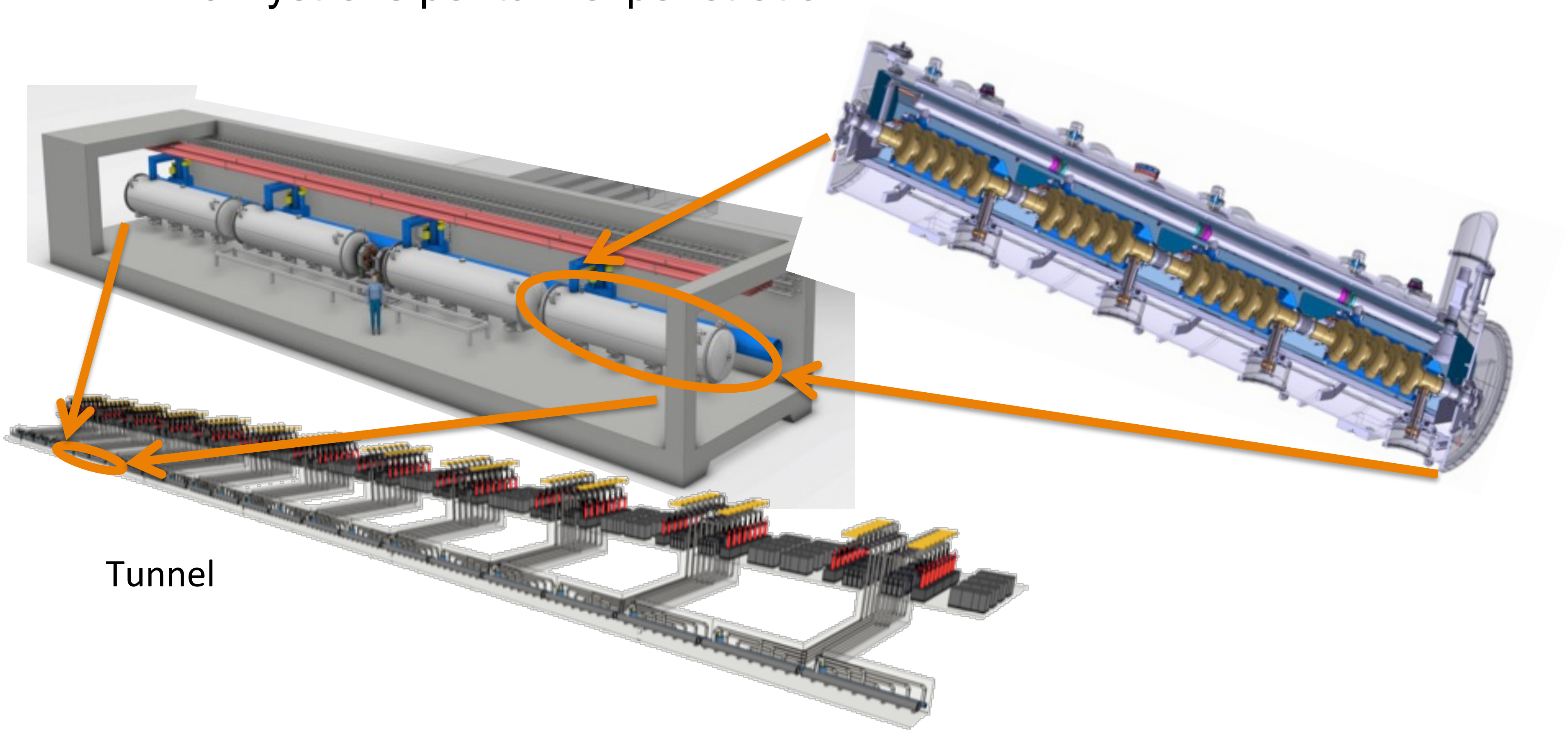


Spoke assembling in clean room/IPNO

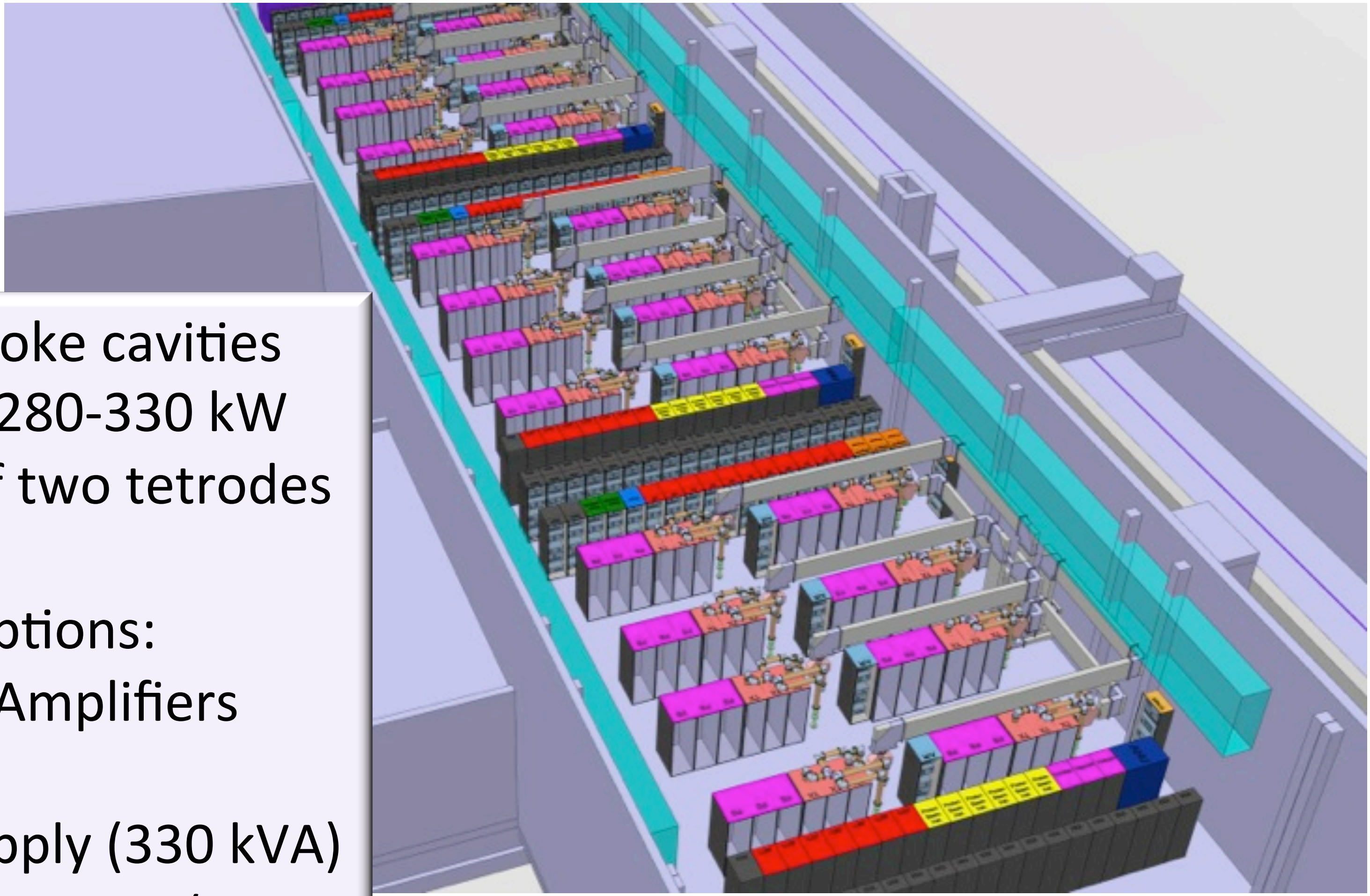


Elliptical (704 MHz) RF System Layout

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



Spoke linac (352 MHz) RF System Layout

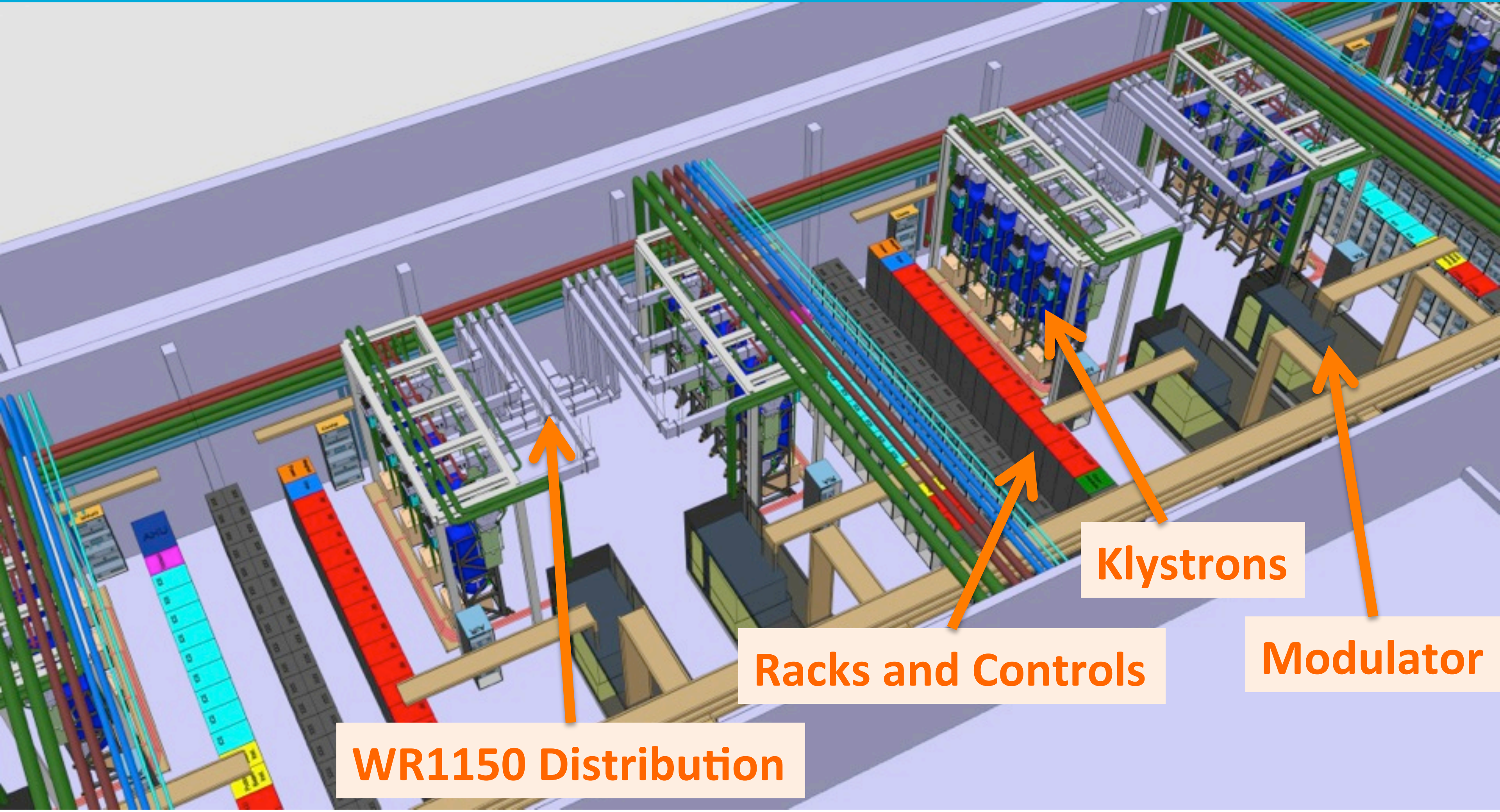


26 Double Spoke cavities
Power range 280-330 kW
Combination of two tetrodes

Other options:
Solid State Amplifiers

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

Elliptical (704 MHz) RF System Layout



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

Klystron modulators

Design and specifications:

- ESS and LTH;

R&D and training of Highly Qualified Personnel:

- LTH (3 MSc thesis, 5 Research associate, 1 PhD thesis starting Jan 2015);

Control system hardware :

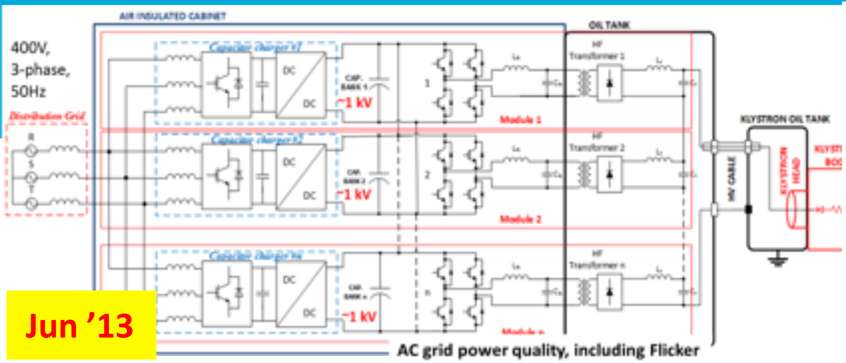
- National Instruments AB, Skåne business center;

Control system software :

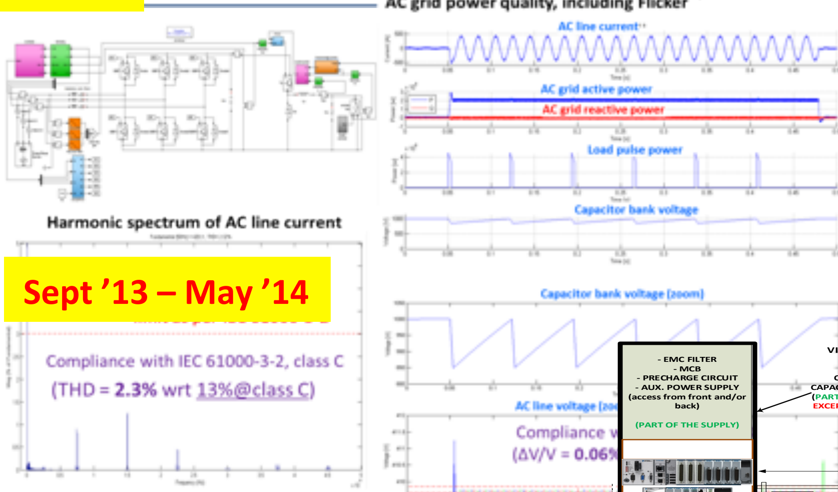
- Lund University Innovation System (LUIS) AB;

Construction (Low Voltage part):

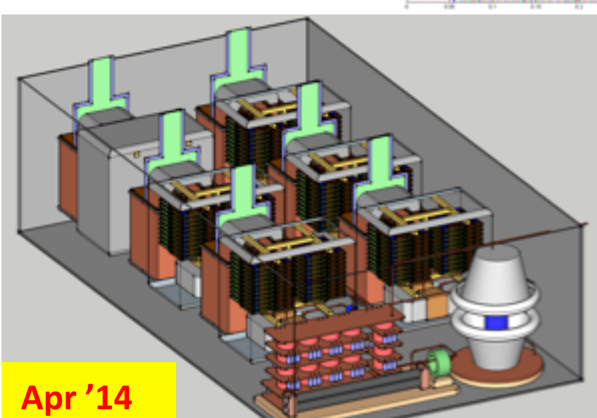
- AQ Elautomatik AB, in Lund;



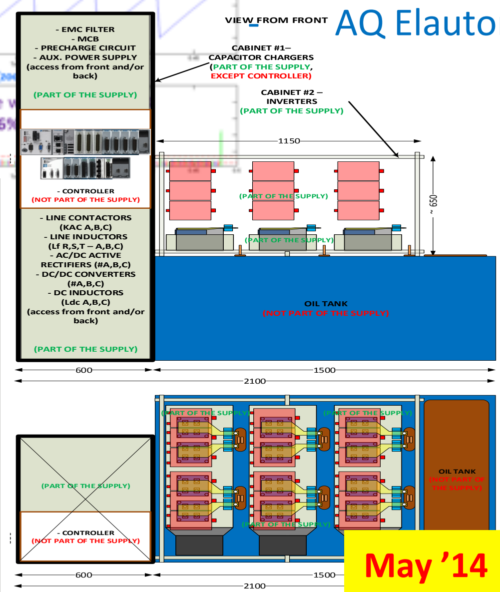
Jun '13



Sept '13 – May '14



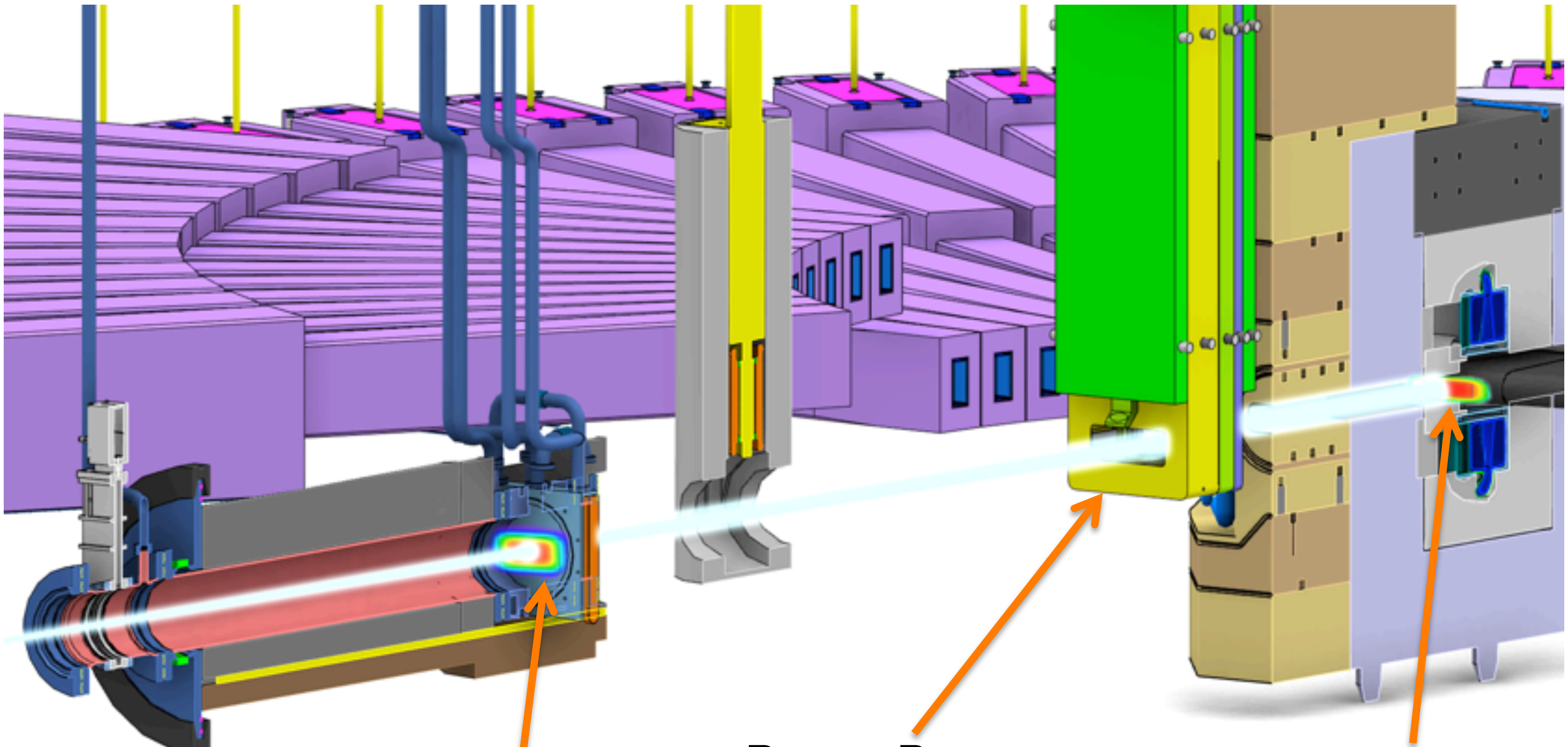
Apr '14



May '14

Aug '14

Beam inside the Target Monolith



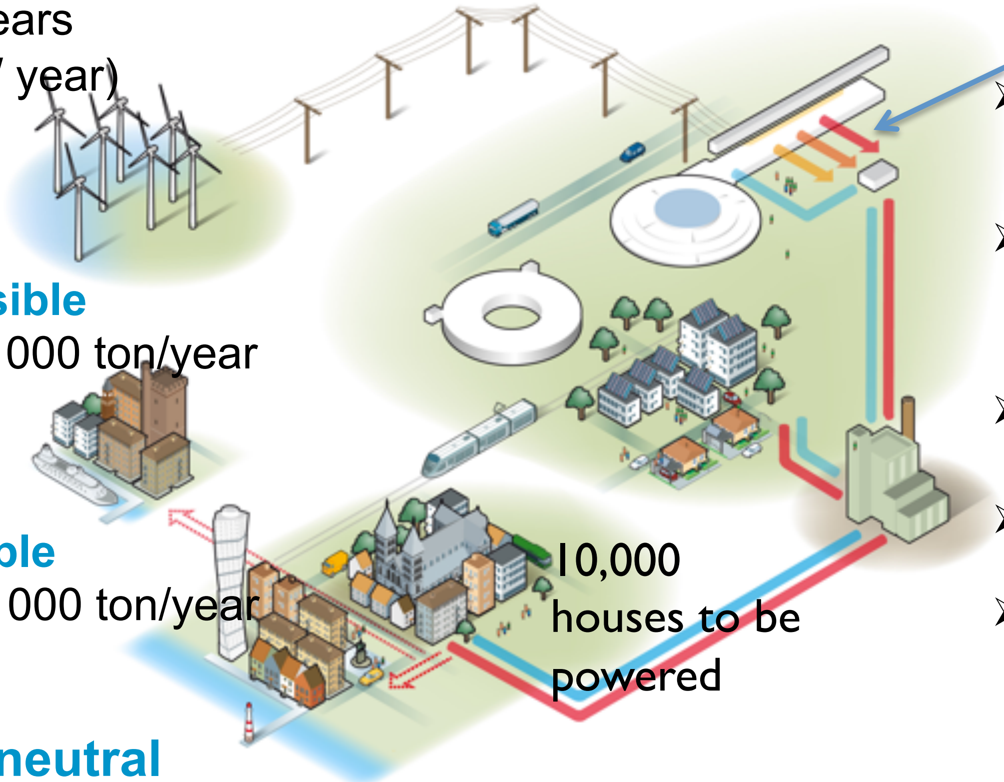
ESS = first sustainable big-science facility

High Efficiency and Minimal Energy Consumption is Mandatory for ESS

Renewable
CO_2 - 120 000 ton/year
For 40 years
(36 MW / year)

Responsible
CO_2 - 30 000 ton/year

Recyclable
CO_2 - 15 000 ton/year



10,000 houses to be powered

CO_2 neutral

Example of Responsible attitude:
Choice of IOT Energy Advantage

- 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

A complementary initiative based on education: The Baltic Accelerator School

BAS2015 summer school will be hold in Lund University from August 17 to 21, 2015.

~20 students at levels between the bachelor's and master's degrees.

The objective is to teach the basics of accelerator physics and technology, and to demonstrate for the students that this is an interesting and broad subject, carried out in an international environment. The initiative shall encourage students to pursue a career in accelerator physics and technology.

Another important aspect is to increase visibility of the lively activities in accelerator physics and technology in Lund (MAX IV Laboratory, ESS and Lund University), Aarhus University, Uppsala University, Oslo University and Jyväskylä University.

The aim of the BAS2015 is also to develop a strategic partnership between European universities and to establish a series of biennial summer school following this first edition.

BAS

Learning outcomes

The course is given by leading researchers in the field. The outcome is that the student shall obtain state of the art competence, corresponding to 3 ECTS, in Accelerator Physics and Technology.

Course contents

Introduction to fundamentals of Accelerator Physics involving classical mechanics, electrodynamics and special relativity; Overview of linear accelerators, storage rings for the generation of light, spallation sources and colliders; Description of radio frequency systems, normal conducting and superconducting magnets, cryogenic systems, vacuum systems, and powering systems; Physics of particle beams: longitudinal and transverse beam dynamics, synchrotron radiation, non-linear beam physics, storage ring lattice design, computational methods in beam physics; Introduction to applications using Accelerator Technology in the field of nuclear and particle physics, materials science, medical applications and biology; New accelerator technologies: research on novel acceleration concepts using powerful lasers in plasmas.

Teaching

The course is given during one week followed by one week of individual problem solving. The preliminary daily layout of the first week is four hours of lectures, two hours of supervised problem solving and tutorials, and finally individual problem solving, where solutions are to be presented the following day. The teachers are continually accessible for discussions and supervision. At the end of the first week, problems corresponding to one week of work, are distributed. The solutions of these should be electronically communicated to the teachers.

The Baltic Accelerator School

University course on Fundamentals on Accelerator Physics

existing course in Department of Electrical and Information Technology (EIT105F)

and equivalence in Dept. of Experimental High Energy Physics

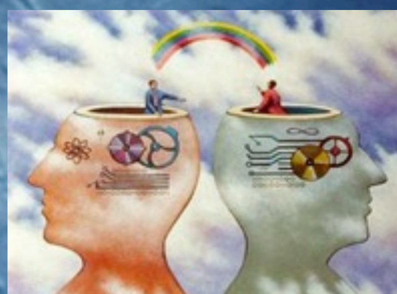
On-line registration

Web side in construction:

http://www.eit.lth.se/index.php?ciuid=922&coursepage=4875&L=0

New Collaborations to Empower ?

Science institutions involved in the design & construction of ESS



Fractality and entanglement

Aarhus University
CEA Saclay, Paris
CNRS Orsay, Paris
ESS Bilbao
INFN, Catania
Lund University
Uppsala University
Accelerator Science and Technology Centre, Daresbury and Oxford
CERN, Geneva
Cockcroft Institute, Daresbury
DESY, Hamburg
ESS Bilbao
Fermi National Laboratory, Chicago

John Adams Institute for Accelerator Science, London and Oxford
Laval University, Canada
Maribor University, Slovenia
National Centre for Nuclear Research, Poland
Oslo University
Rostock University
Spallation Neutron Source, Oak Ridge
Stockholm University
Techical University of Darmstadt
Nuclear Physics Institute Of The Ascr
Czech Technical University, Prague
Aarhus University
University Of Copenhagen
University Of Southern Danmark
Technical University Of Danmark - Dtu
Institut Laue-Langevin - Ill
Llb (Laboratoire Léon Brillouin)
Helmholtz-Zentrum, Berlin
Helmholtz-Zentrum, Geesthacht
Technical University, Munich
Forschungszentrum, Jülich
Elettra-Sincrotrone Trieste
Università Di Perugia
Consiglio Nazionale Delle Ricerche
Delft University Of Technology
Institute For Energy Technology, Ife
Linköping University
Mid Sweden University
Epfl | École Polytechnique Fédérale De Lausanne
Paul Scherrer Institute, Psi

Thank you for your attention