



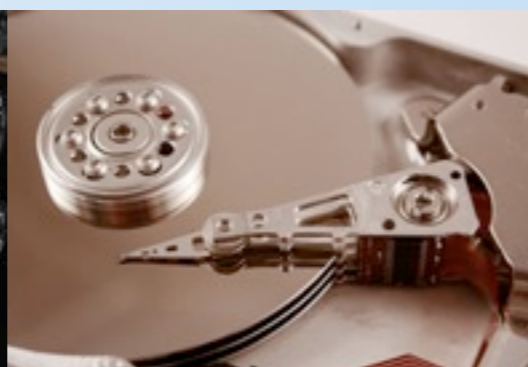
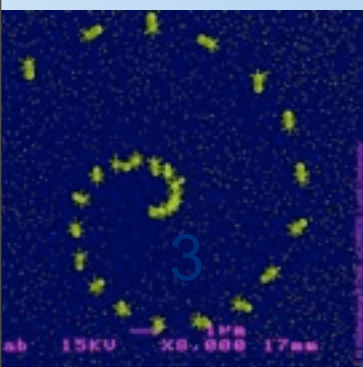
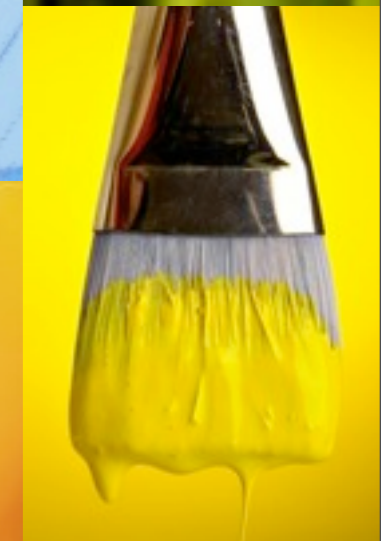
European
Spallation
Source

PLANNED ESS TEST ACTIVITIES

Karin Rathsmann
2010-03-29

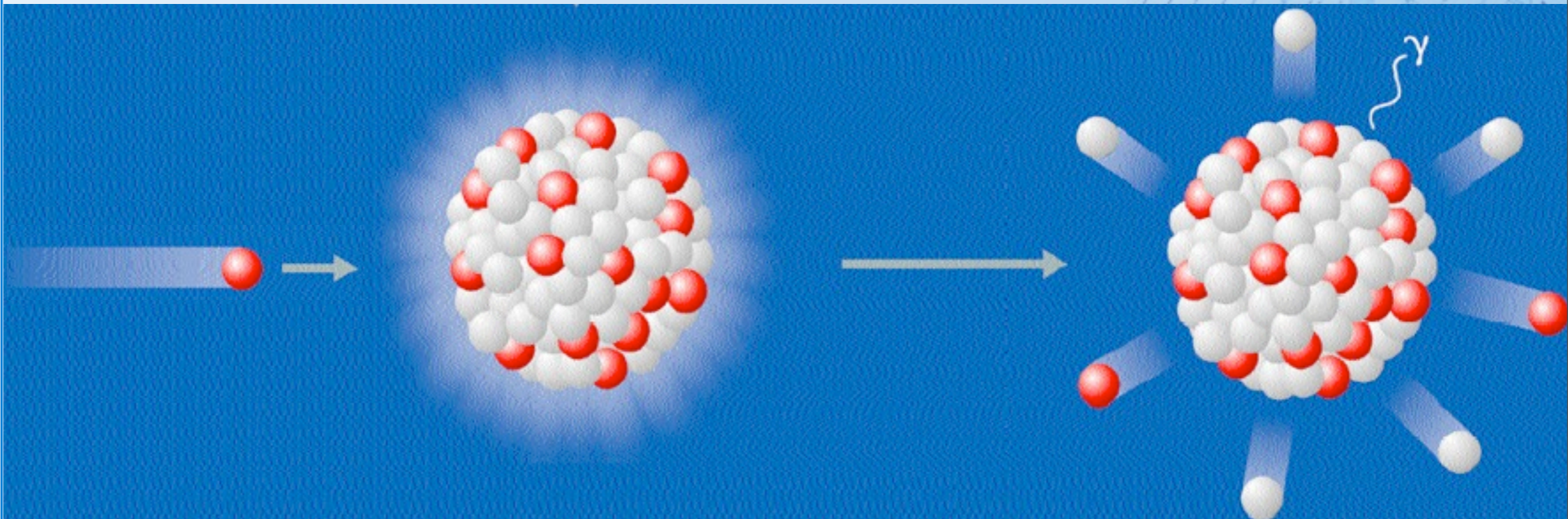
EUROPEAN SPALLATION SOURCE

- ★ A *joint european project* that will become a multi-science research facility.
 - Material Science, chemistry, bio-science, medicine, energy, environment, climate, engineering, archeology, new materials....
- ★ Neutrons are ideal for probing material:
 - They are *neutral* and therefore highly penetrating
 - Their *magnetic* moment can be used to study magnetic structures
 - Neutrons have *spin* and can be formed into polarized beams
 - The *energy* of thermal neutrons are similar to the energies of excitations in solids (vibrations, lattice modes, etc.)
 - The *wavelength* of neutrons are similar to atomic spacing.
 - Neutrons are sensitive to *light nuclei*.



NEUTRON SPALLATION

- ★ A spallation source consists of three major parts:
 - A particle *accelerator* to create projectiles.
 - A *target* where neutrons are spalled.
 - Instruments* (neutron guides and detectors) for the scientists.
- ★ One high energy proton (2.5 GeV) gives many (~40) low energy neutrons
- ★ Multiplication factor scales with energy





5



SNS Oak Ridge 2006





SNS Oak Ridge 2006



J-PARC Tokai 2008



SNS Oak Ridge 2006



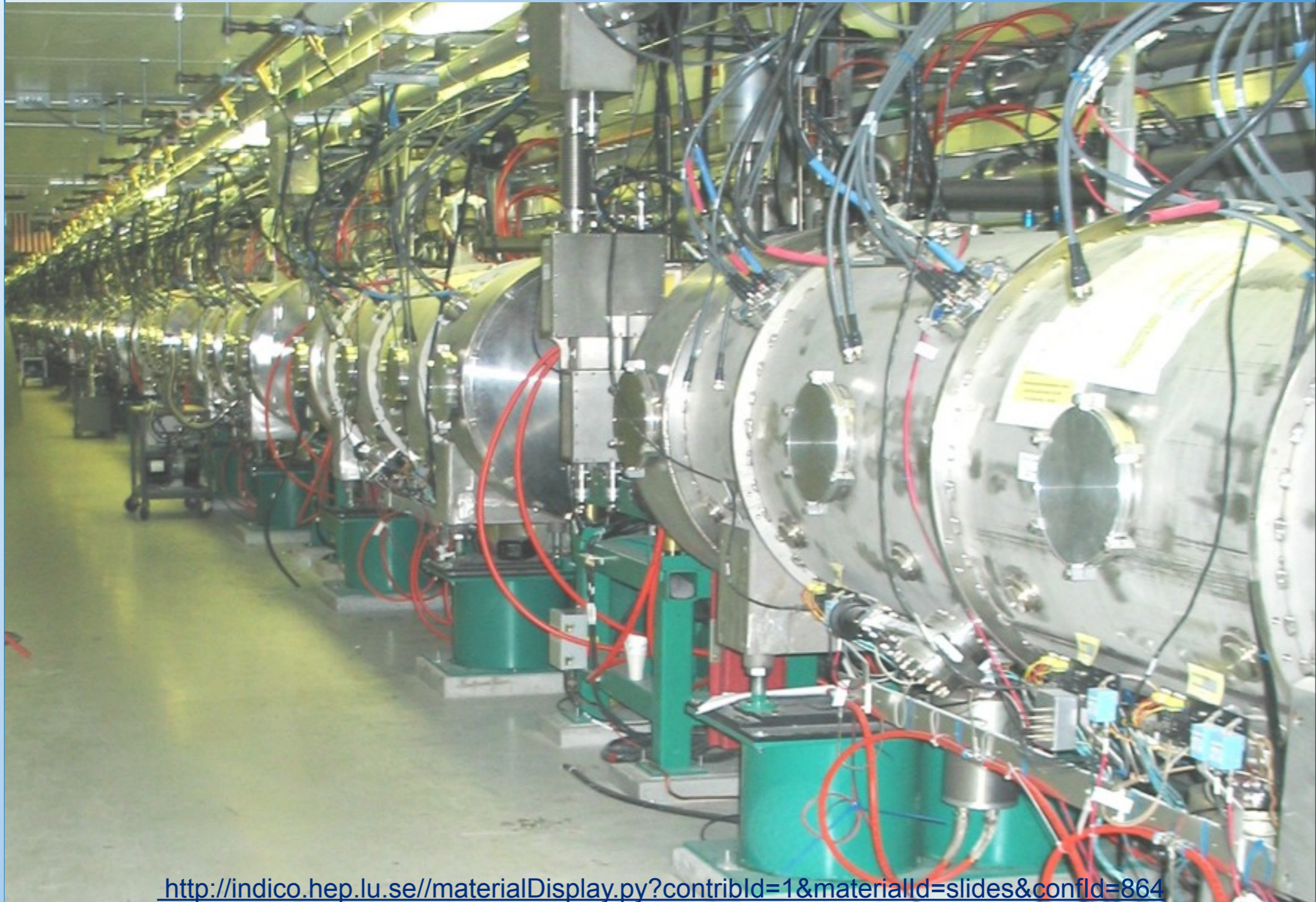
ESS Lund 2019



J-PARC Tokai 2008

SUPERCONDUCTING LINAC

SNS Oak Ridge



LIQUID METAL TARGET

SNS Oak Ridge



INSTRUMENTS

SNS Oak Ridge



STATUS

- ★ ESS has a high priority on the ESFRI list
 - “To ensure that Europe has access to world leading facilities, the *European Spallation Source (ESS)* is a *high priority* together with the upgrade of the Institut Laue-Langevin (ILL).”
- ★ Lund elected as the site for ESS at a Ministerial meeting in Brussels 28 May 2009
- ★ ESS *Scandinavia*, ESS *Bilbao* and ESS *Debrechen* has become ESS, which now has 14 member states.
- ★ First Steering Committee meeting in Copenhagen 22-23 October 2009
- ★ New organization from April 1, 2010
- ★ First neutrons for 2019 with full design specifications in 2023



SITE OVERVIEW

COPENHAGEN ==>

MALMÖ

LUND

MAX IV

ESS

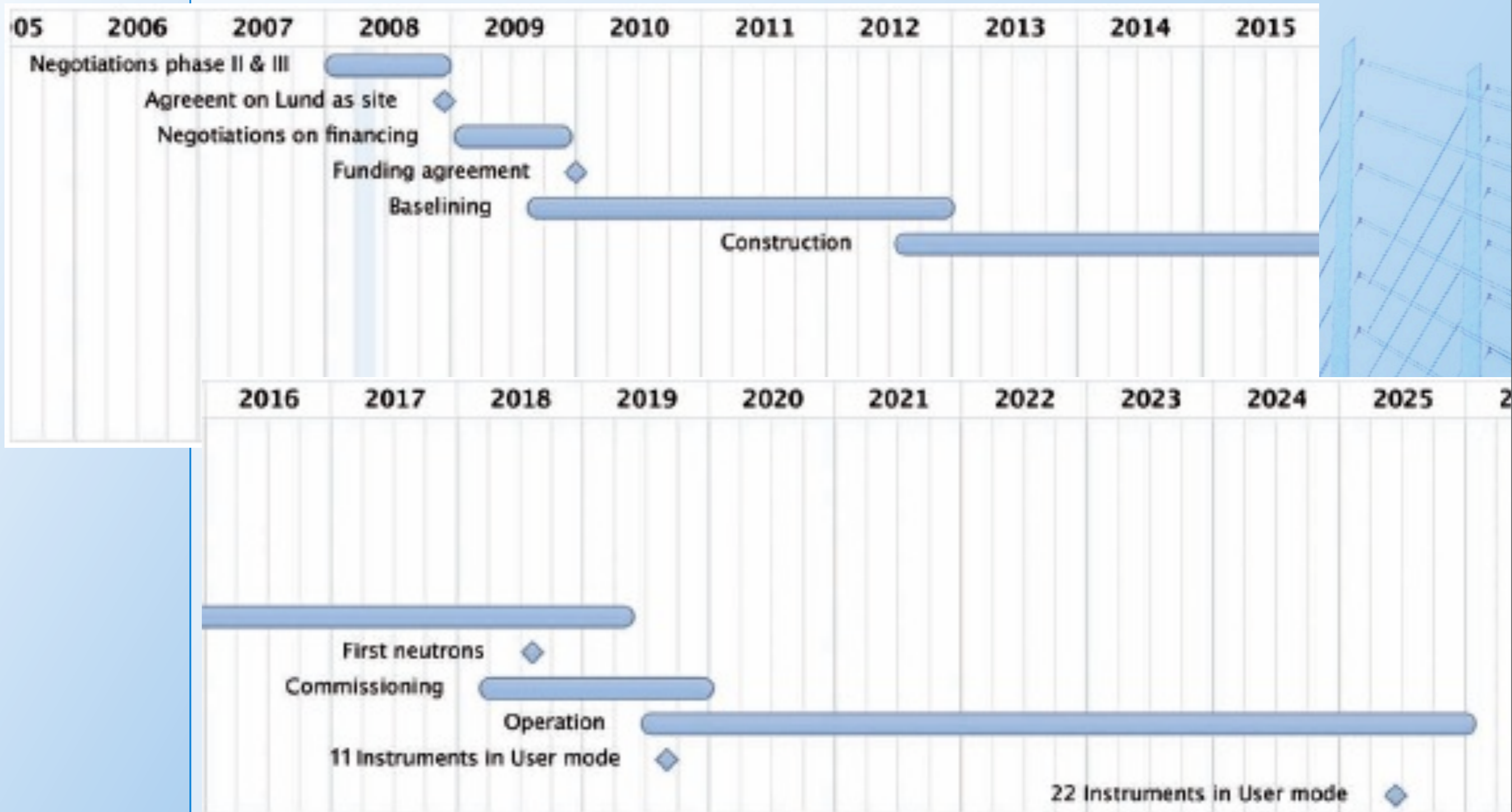
Instruments

Target

Linac

TIME LINE

Ambitious goals requires ambitious planning



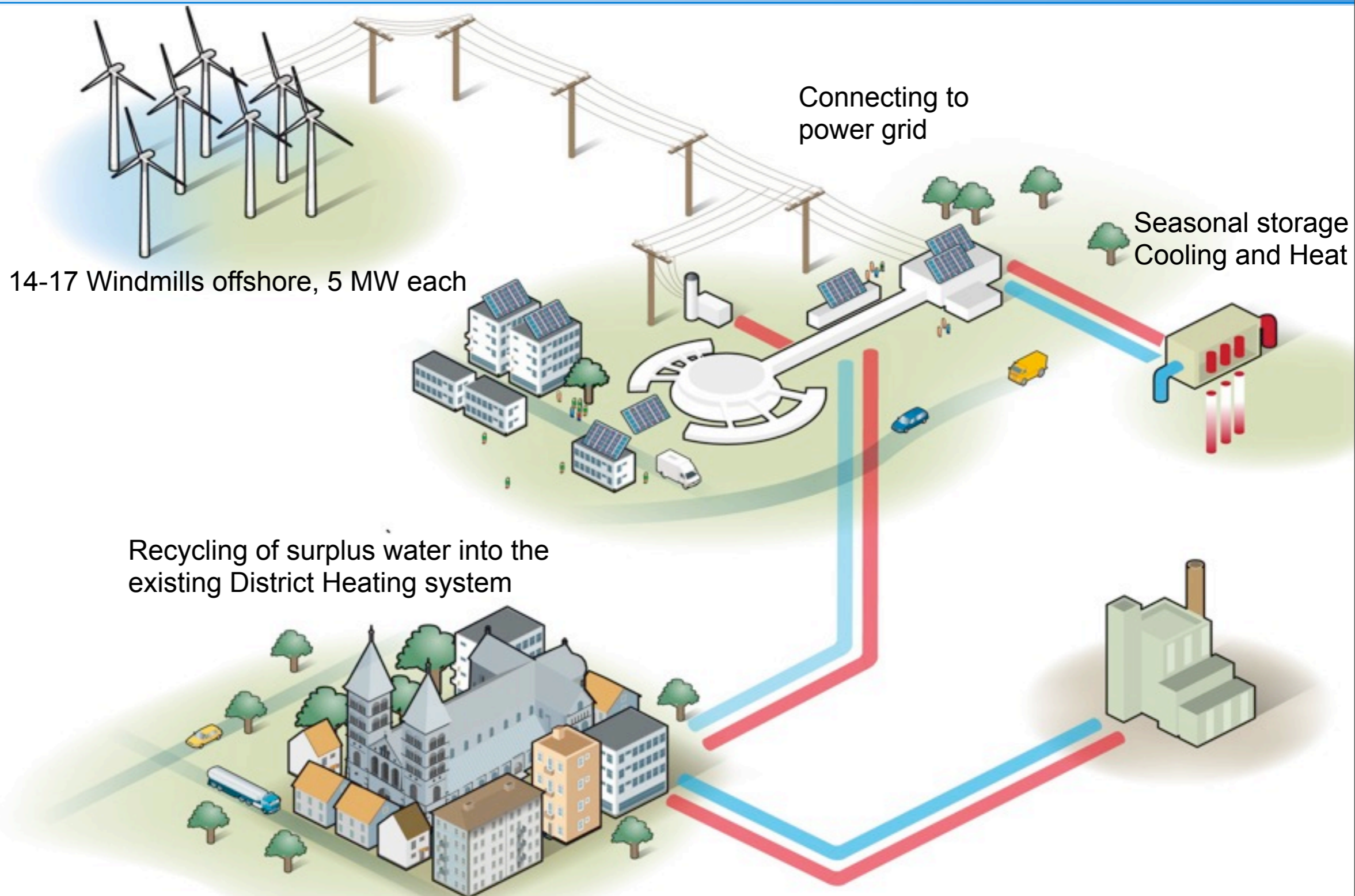
ESS GUIDELINES

(Adopted by the ESS Steering Committee)

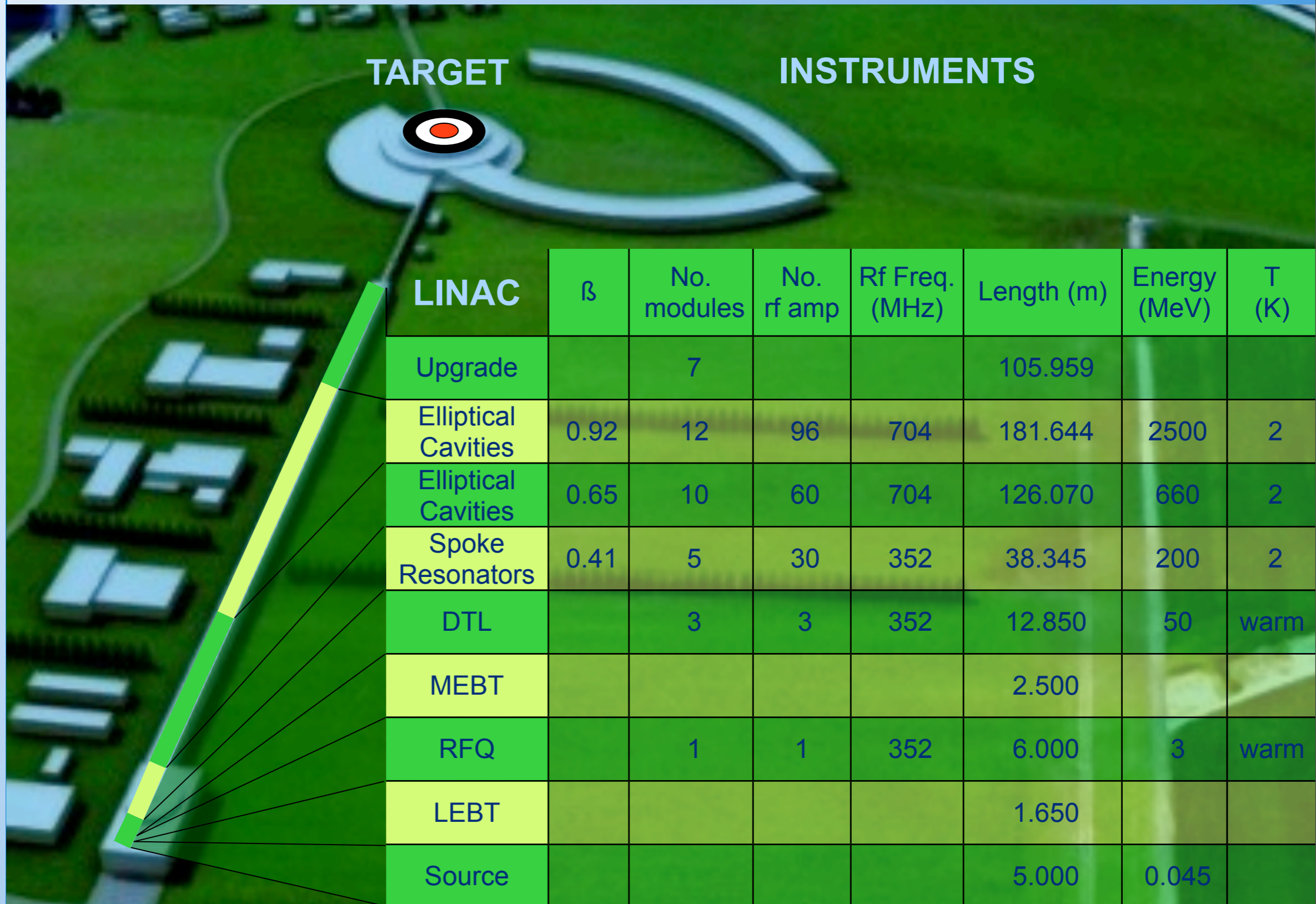
- ★ Starting point is the 2008 ESFRI Roadmap specification
- ★ Performance parameters
 - Neutron production 30 times SNS today
 - Peak neutron flux 30 times ILL's average flux
 - Time-averaged flux equal to ILL
- ★ Electrical power supply 32 MW to 38 MW
- ★ Accelerator key parameters
 - A proton linac
 - Proton energy range: 1 to 2.5 GeV
 - Pulse frequency range: 10 to 20 Hz
 - Pulse length range: 0.8 to 2 msec
 - Nominal beam power: 5 MW
 - Beam on target: > 95 % reliability
 - Beam loss: ~ 1 W/m
- ★ Target station key parameters
 - A single target station
 - Cold and cold-thermal moderators
 - A liquid metal target: mercury or lead-alloys, Solid rotating target as fall-back
- ★ 22 beam ports (11 North, 11 South)
 - or 11 beam ports South and 22 neutron guides North.

SUSTAINABLE RESEARCH CENTER

Responsible-Recyclable-Renewable



LINAC OVERVIEW



WORK PACKAGES

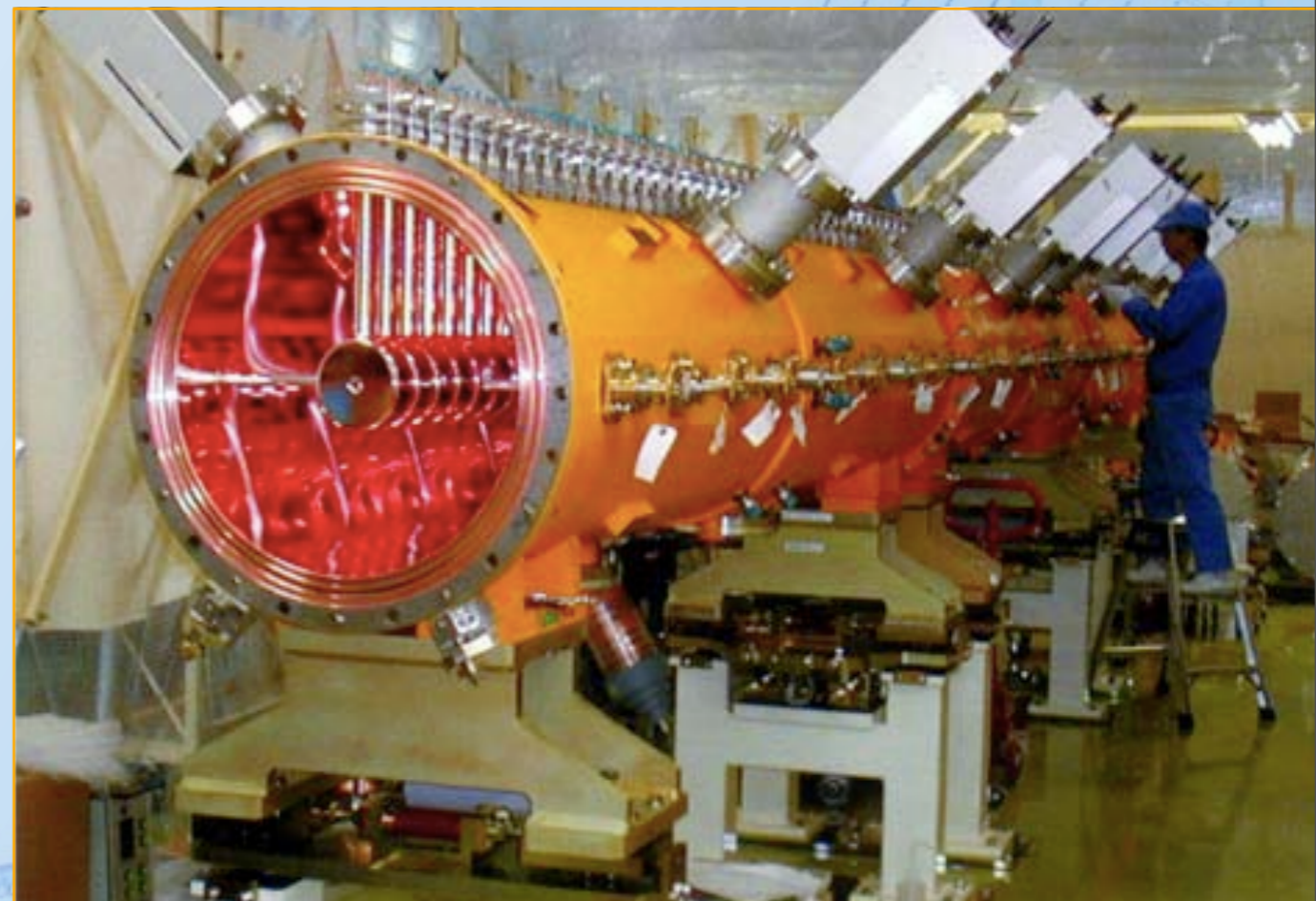
1. Management and Coordination
2. Accelerator Science
3. Infrastructure Services
4. SCRF Spoke cavities
5. SCRF Elliptical cavities
6. Front End and NC linac
7. Beam transport, NC magnets and Power Supplies
8. RF Systems

FRONT END & NC LINAC

WP 6

★ Work units of WP6:

1. Planning of the activities
2. Source and Low Energy Beam Transport (LEBT)
3. RFQ
4. Medium Energy Beam Transport (MEBT)
5. NC Linac



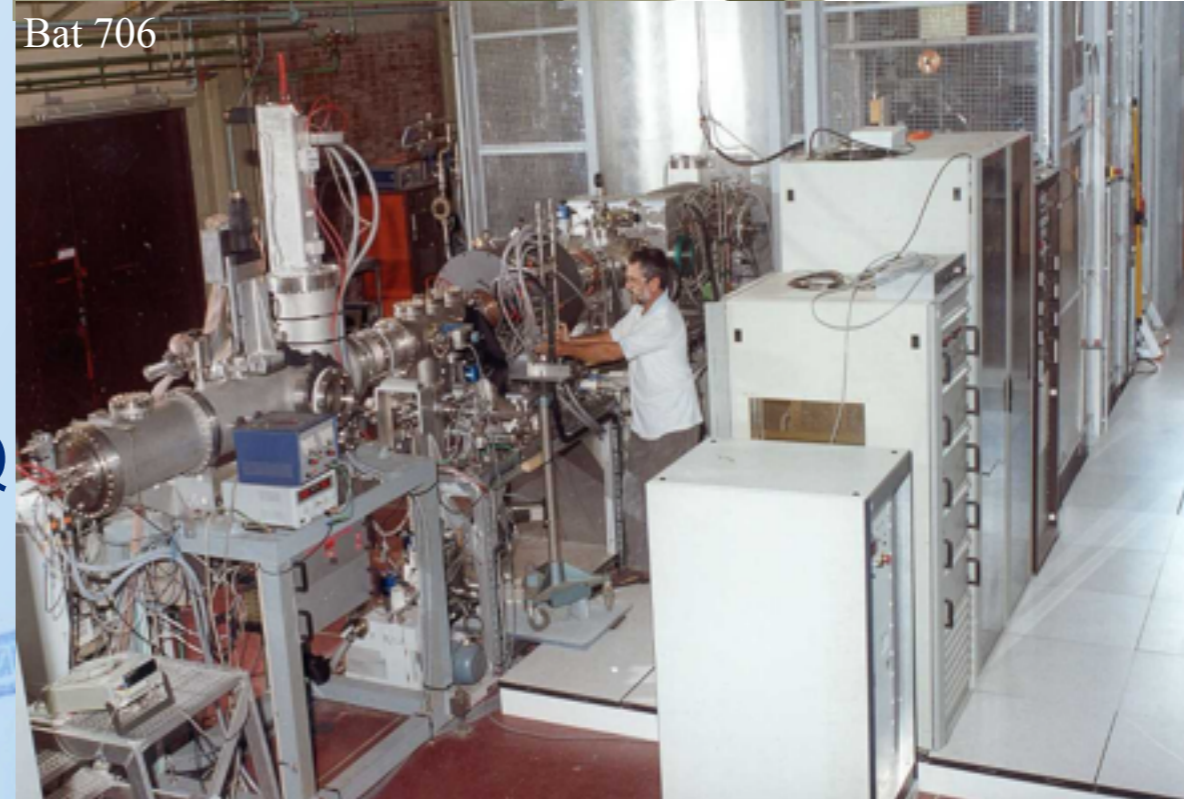
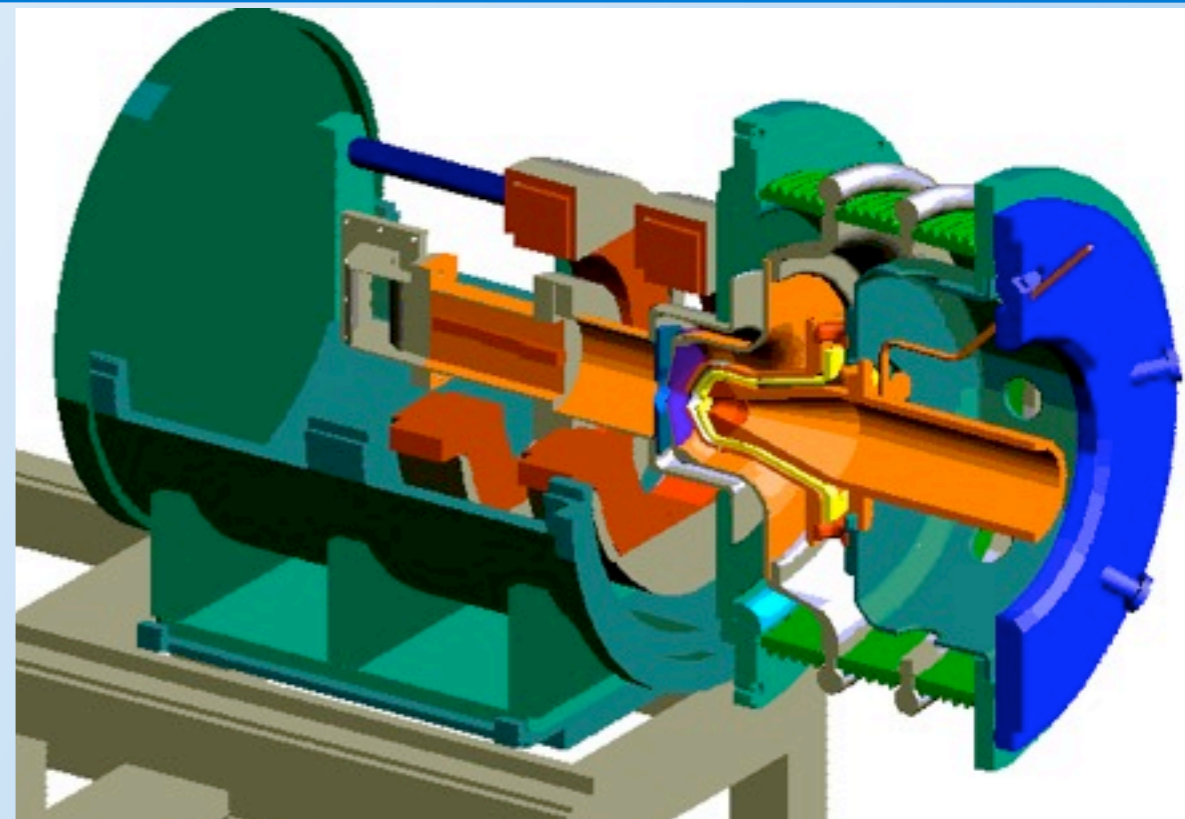
SOURCE AND LEBT

★ SILHI:

- H⁺ Intensity > 100 mA at 95 keV
- H⁺ fraction > 80 %
- Beam noise < 2%
- 95 % < Reliability < 99.9 %
- Emittance < 0.2 π mm.mrad
- CW or pulsed mod

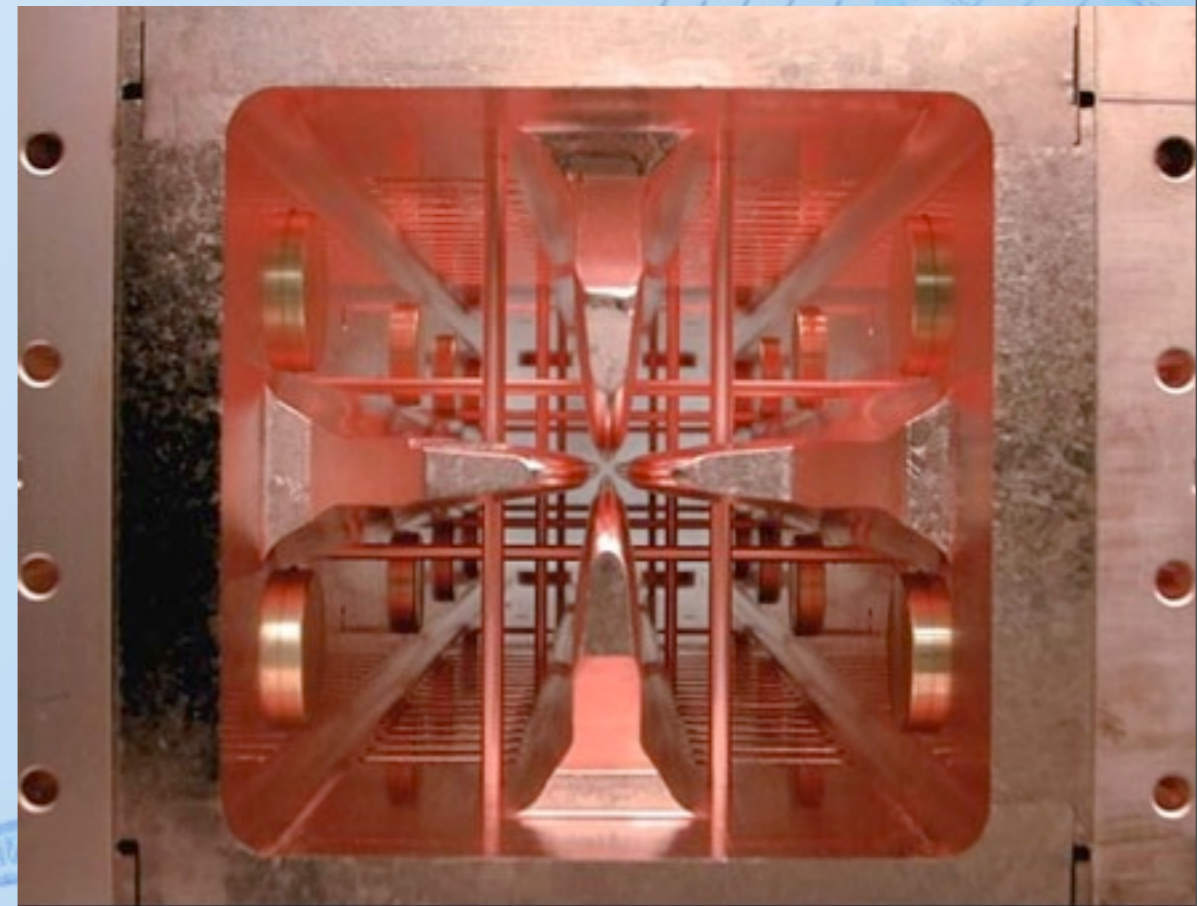
★ Study of pulsed operation with existing sources at INFN-LNS and CEA-IRFU

★ Study of matching with RFQ



WHO MASTERS RFQ?

- ★ SNS: problem with the tuning during operation.
- ★ J-PARC: high sparking rate, they are replacing it and are switching to a 4 vanes structures
- ★ Study of operations with exiting RFQ at CEA-IRFU



http://commons.wikimedia.org/wiki/File:SNS_RFQ.jpg

BILBAO TEST STAND

ETORFETS: a Front End Test Stand for ESS-Bilbao

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ABSTRACT

The ETORFETS project aims at building a front end test stand as part of the R&D effort of the ESS-Bilbao Consortium. The main objective is to set up a facility to demonstrate experimentally the design ideas for the future ESS LINAC that are being proposed in discussion forums in the technical scientific community. In this sense, ETORFETS is carried in the first stage of acceleration of the linear accelerator, namely, that of the Radio Frequency Quadrupole and its pre and post beam transport systems.

The current ETORFETS consortium is coordinated by ESS-Bilbao Consortium and is composed by TECNOR S.L (research center), EIZTI (EMERG) and JEMIA GROUP (Industrial company), The University of the Basque Country, CSIC-Spanish Scientific Research Council and CEMAT (Spanish Scientific institution).

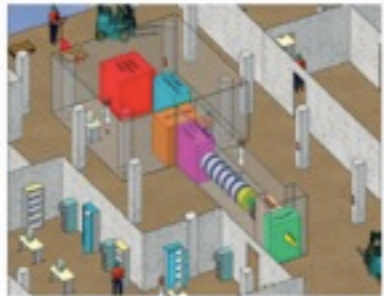
*The technical viability is guaranteed by the collaboration between the project consortium and several scientific institutions such as CERN (Switzerland) and INFN - Orsay (France).

OBJECTIVE

The main objective is to develop FETS - Bilbao infrastructure, namely the elements and systems building and services included that generate, accelerate, guide, focus and chop ions, together with diagnostic instruments and final absorption and stop. At least a conceptual design phase will be carried out to define the sequence of room temperature and superconducting cavities of a complete LINAC. As a consequence of the development of the project specific technologies of particle accelerators are required.

The objective of such a FETS is to demonstrate the production of chopped beams of hydrogen ions of high quality:

- 60 mA
- 3 MeV
- Up to 2 ns of pulse length
- Up to 50 ppm of repetition rate



MAIN COMPONENTS OF THE FETS-BILBAO

There are several areas that can be defined in a Front End, corresponding to specific systems and technologies. Here is the full list:

- **Ion Source:** Its mission is to obtain hydrogen ions, H⁺ in the first approach and then also H⁻, requirements are minimum emittance, maximum performance, high reliability-availability, high % production of desired particles, stability and compactly of high brilliance (see TURL poster).
- **Low Energy beam Transport (LEBT):** section where particles originated in the source are focused and directed to the following stages. It is fundamental to be well equipped with instruments, since the whole chain of subsequent acceleration systems depends on beam quality at the exit of this device.
- **Radiofrequency Quadrupole (RFQ):** It is responsible for grouping particle beams (bunching), focusing them and accelerating them. Its main requirements are high efficiency in bunching, low particle losses, reliability and compactly.
- **High Speed Chopper:** "tamper" type for fulfilling specific requirements such as short ramping time (3ns) and long permanence time (up to 100µs).

Beam Diagnostic Elements:


One of the key factors of the FETS facility is its instrumentation, since in order to characterize beam parameters, a series of measuring devices are required.

Beam stop:

System for stopping, absorption and refrigeration of the beam.

Beam Diagnostic Elements:


Choppers work by applying a high voltage on the beam, in order to remove part of it. The greatest challenge is for a Chopper to be able to commute this voltage very quickly, that is, between ion bunches (just a few ns) and then keep it for a longer time (µs), so that the required gap is produced between bunches. This contradictory requirement is obtained by a double phase chopper, the fast phase and the slow one.



DIAGNOSTICS

A set of instruments is required to measure beam parameters and evaluate the quality of the beam produced. Typical measurements include:

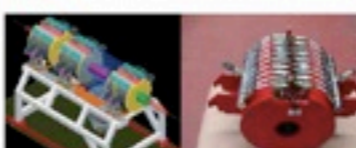
- Beam Current, with current transformers
- Emittance, with emittance scanners
- Beam profile, with Pepper-Pot type instruments
- Degree of stripping, with diagnostic dipoles
- Etc.



THE LEBT

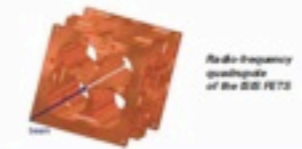
Focusing low energy particle beam is not an easy task. The LEBT has to compensate the space charge effect that pushes the beam to expand itself. Before the beam is driven to the first acceleration phase it needs to be "contracted". In order to do it a series of cylindrical magnets of considerable length have to be used (see the solenoids of the figure). As the beam travels across the solenoids it is forced to follow a spiral movement. This movement not only keeps the beam on the right direction but also compresses its size so that it fits with the RFQ.

It is possible carry out the same focusing operation by electronic methods. A study will be conducted in order to find out the most suitable method.




THE RADIO FREQUENCY QUADRUPOLE (RFQ)

The radio frequency quadrupole is the element responsible for "bunching" and accelerating the ions that come out of the LEBT by intense radiofrequency fields generated by klystrons or tetrodes. The RFQ "bunches" the ion flux softly and later it accelerates it. This soft bunching succeeds in keeping more than 95% of the ions and keep the beam quality. If bunching is performed in a more clumsy way, beam quality may deteriorate and lead to beam losses which reduce systems that come in subsequent phases.



MEDIUM ENERGY BEAM TRANSPORT AND CHOPPERS

Ions come out of the RFQ in bunches close to each other, separated by a few nano seconds. In some applications (Neutrino Factories, Spallation Sources, ADS), these ions experience several acceleration phases in drift tubes, superconducting cavities and other systems. In those applications where the shape of the pulse is important, each of these bunches is chopped by means of an electromagnetic device able to create a time gap, of just micro seconds, between bunches. This is achieved by the use of a line of "choppers". The chopper line of the MEBT consists of a series of quadrupole, RF bunching cavities and the beam chopping system.



BEAM STOP

In order to "dispose of" the beam a beam-dumping system is required. These are usually called beam stops. The beam stop needs to have the following features:

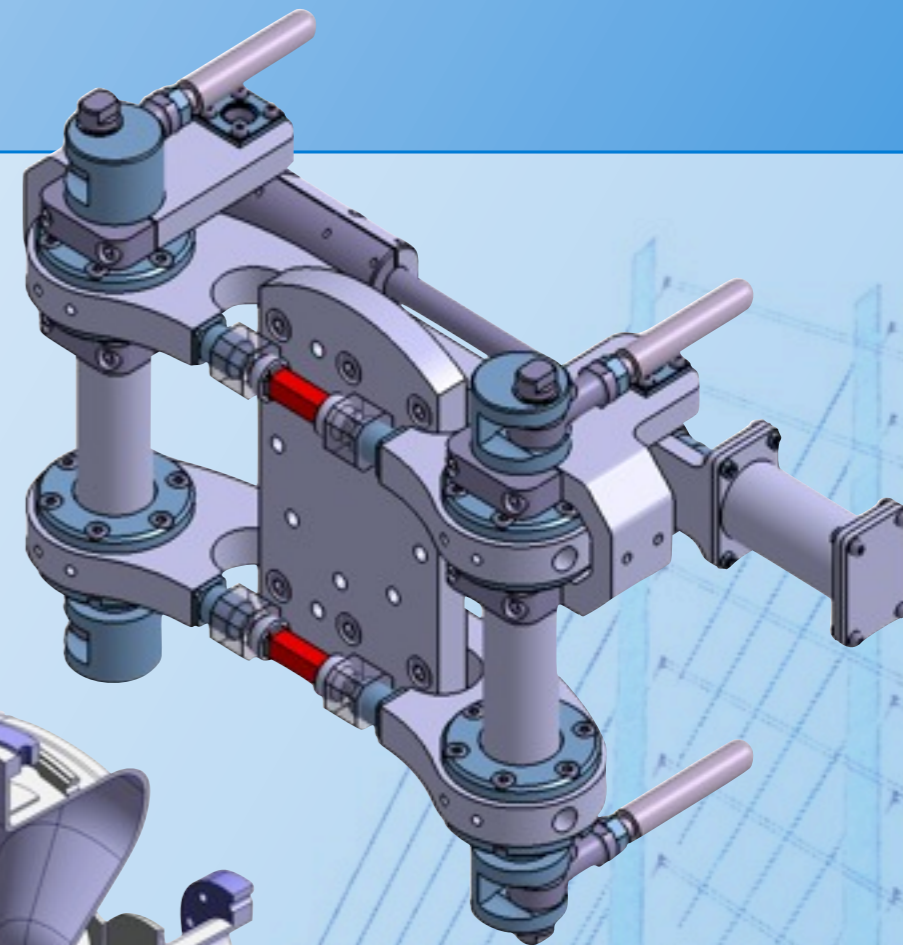
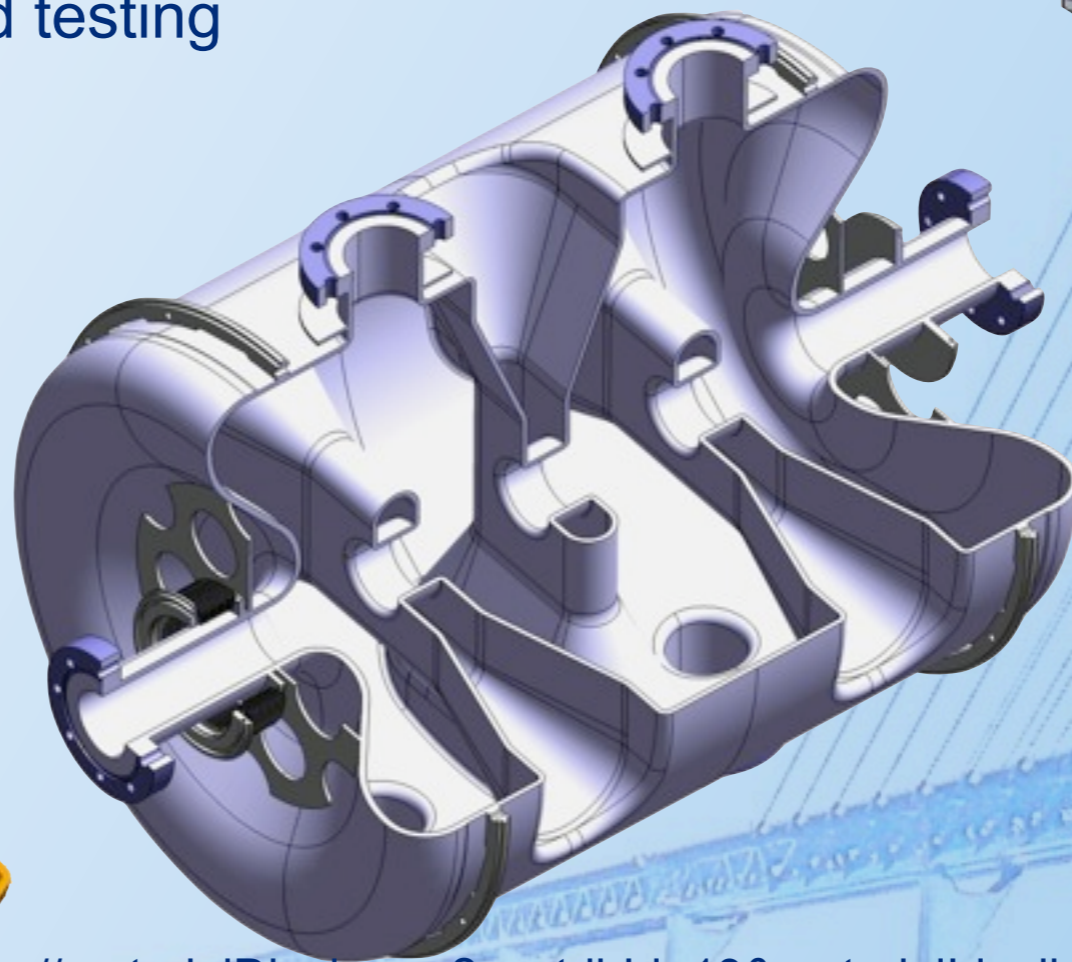
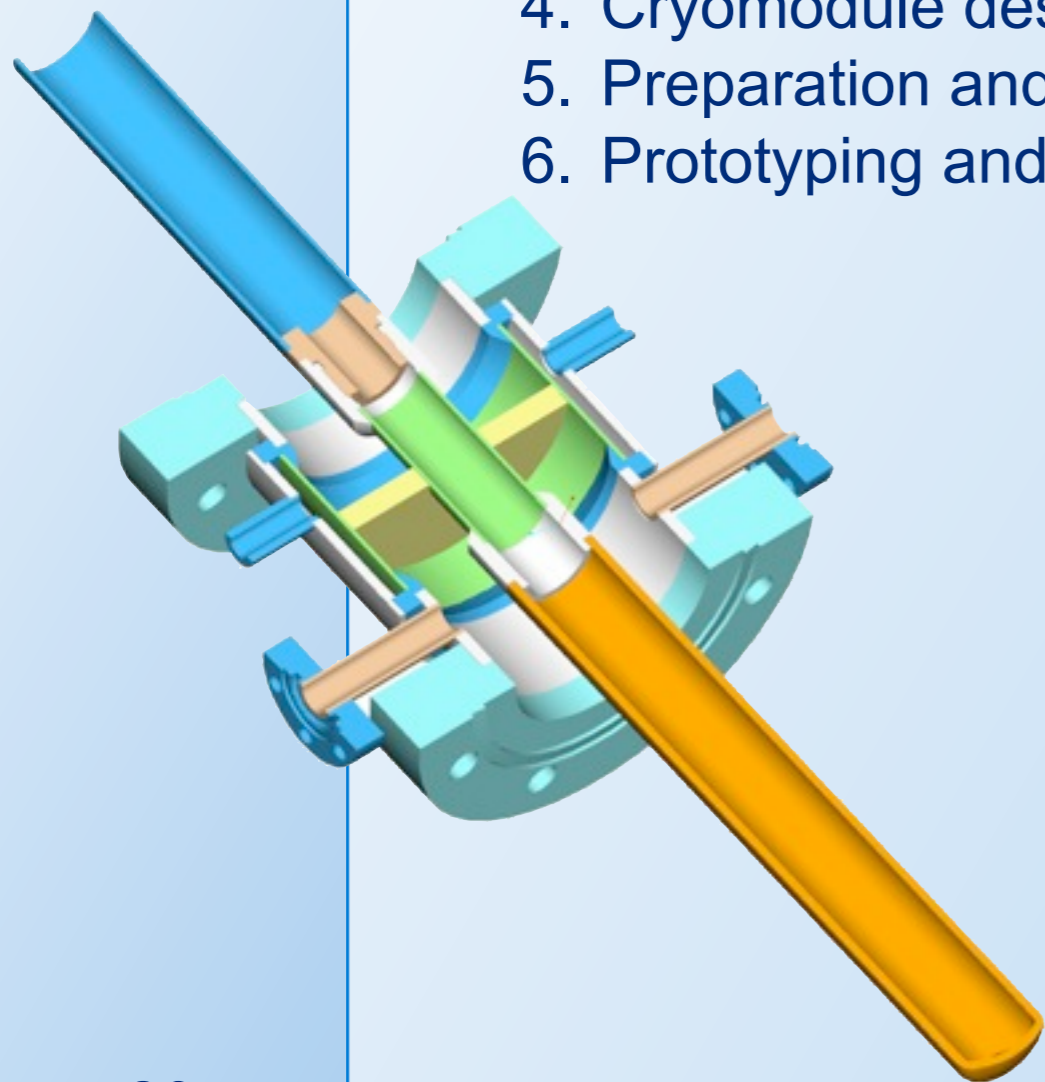
1. Be made of a material that absorbs the radiation generated in the contact between the beam and the beam stop wall.
2. Have a shape that optimizes the heat spread on the beam stop wall. They are usually of conical or, even, sphero shape. This is important to reduce peak temperatures that may affect the mechanical properties of the beam stop material. In addition, refrigeration on its outside wall is usually required to evacuate the heat.
3. Be made of a material subjected to a treatment so that its mechanical properties withstand the mechanical, thermal and fatigue stresses generated on the beam stop surface due to the vacuum pressure inside, the refrigerant pressure outside and the temperature rise (made worse by a temperature change cycle in pulsed beams) by the heat transfer between the beam and the beam stop wall.

SCRF SPOKE RESONATORS

WP 4

★ Work units:

1. WP management and TDR preparation
2. Spoke cavity design
3. Fundamental power coupler design
4. Cryomodule design
5. Preparation and conditioning procedures
6. Prototyping and testing



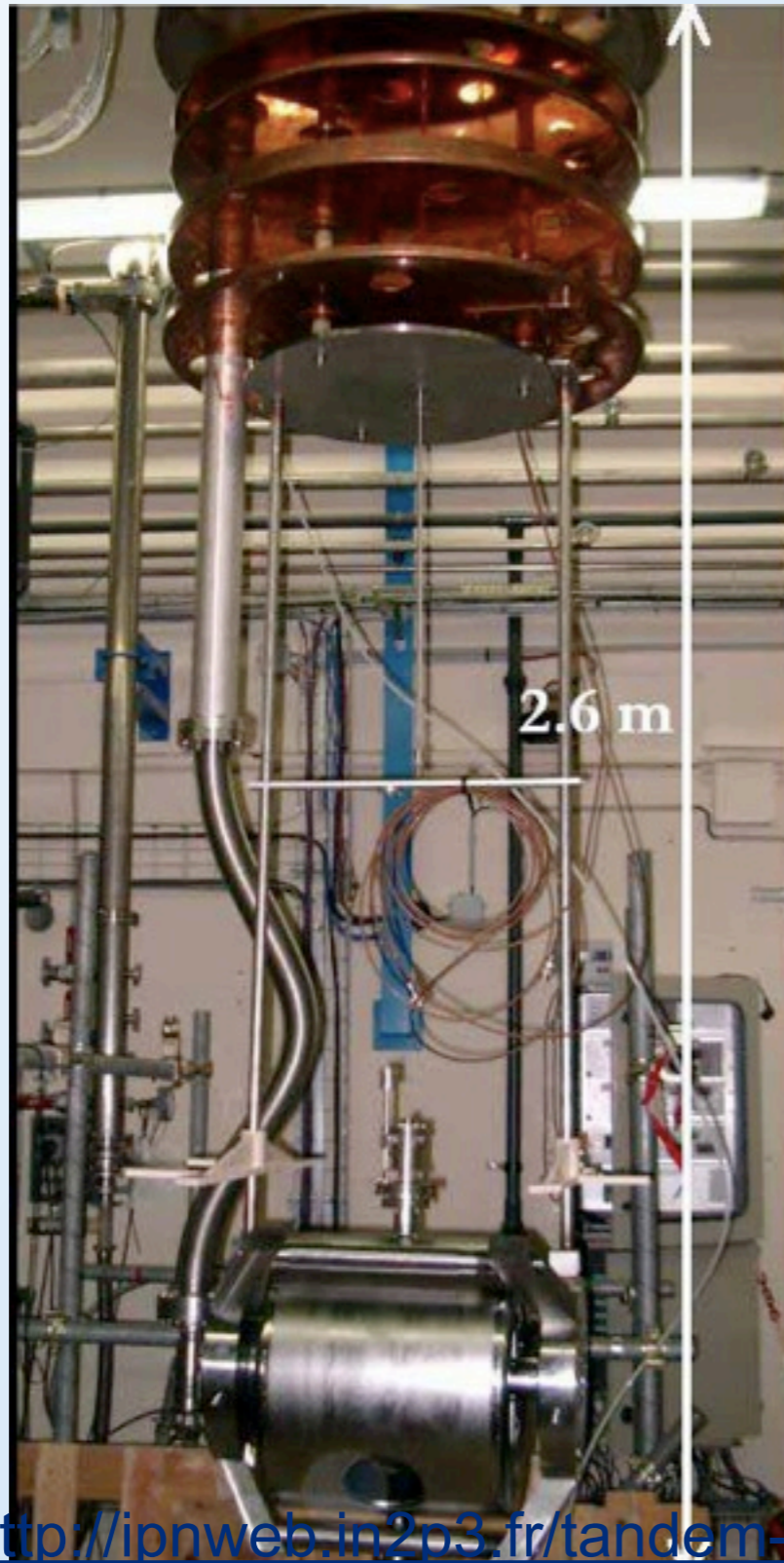
SCRF SPOKE RESONATORS

WP 4

- ★ One of the highest risk components of the ESS Linac
 - High priority to the non-beam testing of early SR Prototypes
 - 2 spoke prototypes, one for each beta,
 - Bare cavities (maybe not fully optimized in terms of mechanical behaviour).
 - Test at least one cavity with the other beta, but only in a vertical cryostat.
- ★ Baseline temperature is 4K, but 2K option will be studied.
 - 2K cryogenics will be available at ESS.
 - Fabricated and tested cavities at low power in VC at 4k and 2K
- ★ 2 prototype power couplers, fabricated and characterized
- ★ No appropriate full cryomodule test stand currently exists.
 - Key element that has to be fabricated and tested before construction is a complete spoke cryomodule prototype (7-8 cavities).
 - Should be tested at low temperature, with the nominal RF power on at least one cavity at a time.

VERTICAL TEST STAND

CNRS Orsay

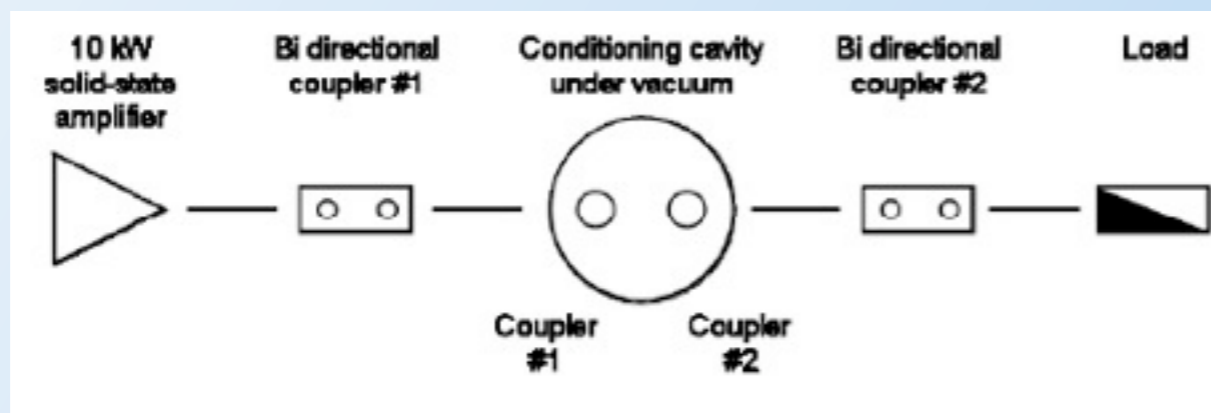
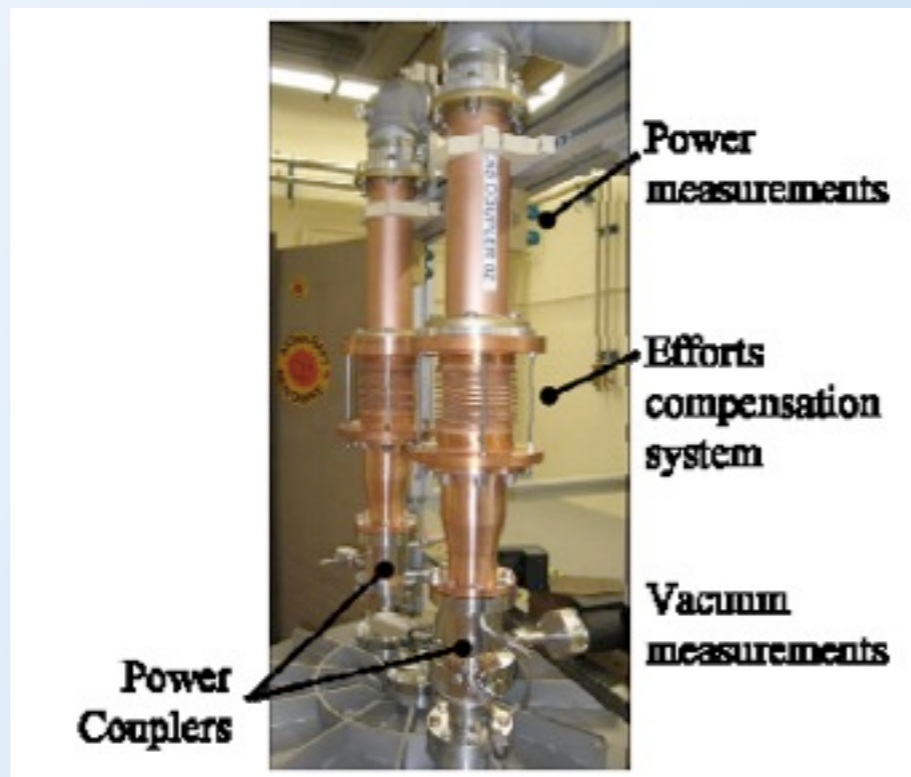


CAVITY PROTOTYPING OUTCOMES

- ★ Assess the fabrication procedure, and evaluate the tuning procedure, check the capability of reaching the desired frequency, evaluate the major difficulties during fabrication.
- ★ Assess the preparation procedure (chemistry, baking, clean room assembly)
- ★ Test in vertical cryostat (at 4K and 2K) and assess the cavity performances (accelerating field, Lorentz forces detuning coefficient, dissipated power) at the two temperature

CONDITIONING TEST STAND

CNRS Orsay



POWER COUPLERS PROTOTYPING OUTCOMES

- ★ Assess the fabrication procedure, evaluate the major difficulties during fabrication.
- ★ Measure the couplers main parameters
-f, S-parameters...
- ★ Assess the preparation procedure
-cleaning, clean room assembly

SCRF ELLIPTICAL CAVITIES

WP 5

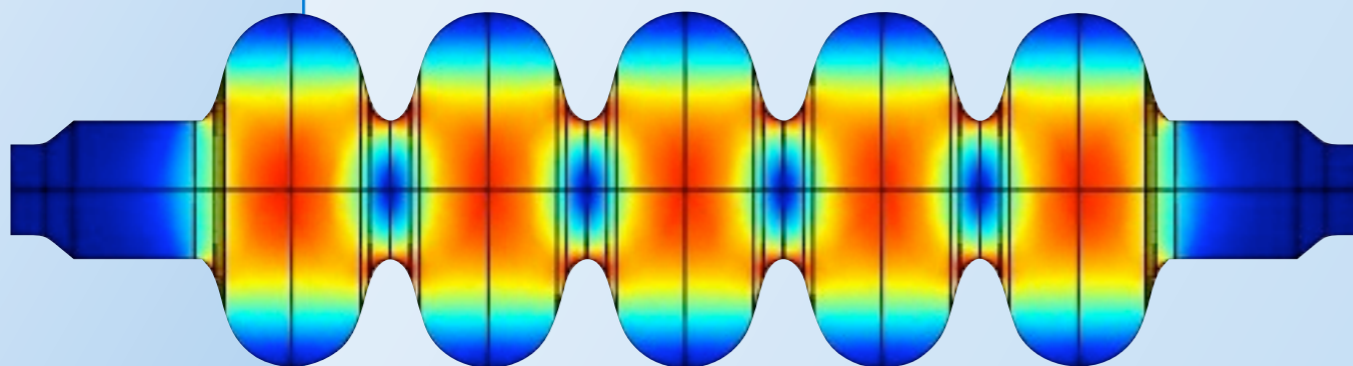
★ Components:

- Cavity incl. power coupler, He vessel, HOM dampers, Tuners
- Intercavity elements
- Thermal and magnetic shields
- Internal supporting and alignment
- Internal cryogenic distribution
- Vacuum vessel

★ Interaction with similar developments

ELLIPTICAL CAVITIES

- ★ 704.4 MHz
- ★ Two geometrical structures
 - $\beta=0.65$
 - $\beta=0.92$
- ★ ESS and SPL and eRHIC:
five cell cavity

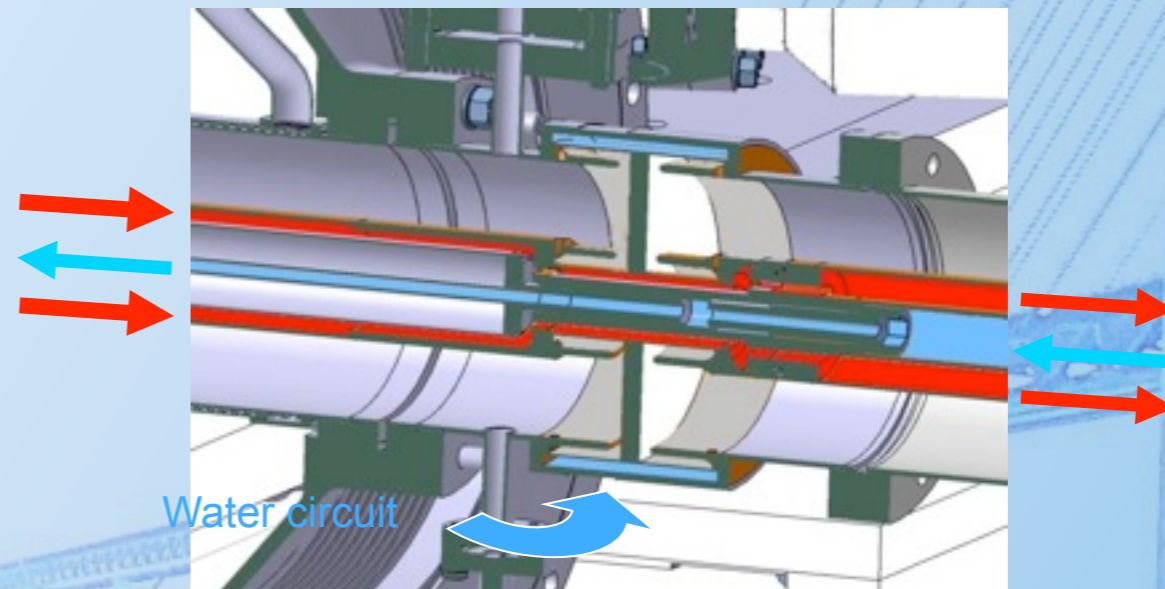


eRHIC 704MHz cavity, $\beta=1$
(AES brookhaven)

POWER COUPLERS

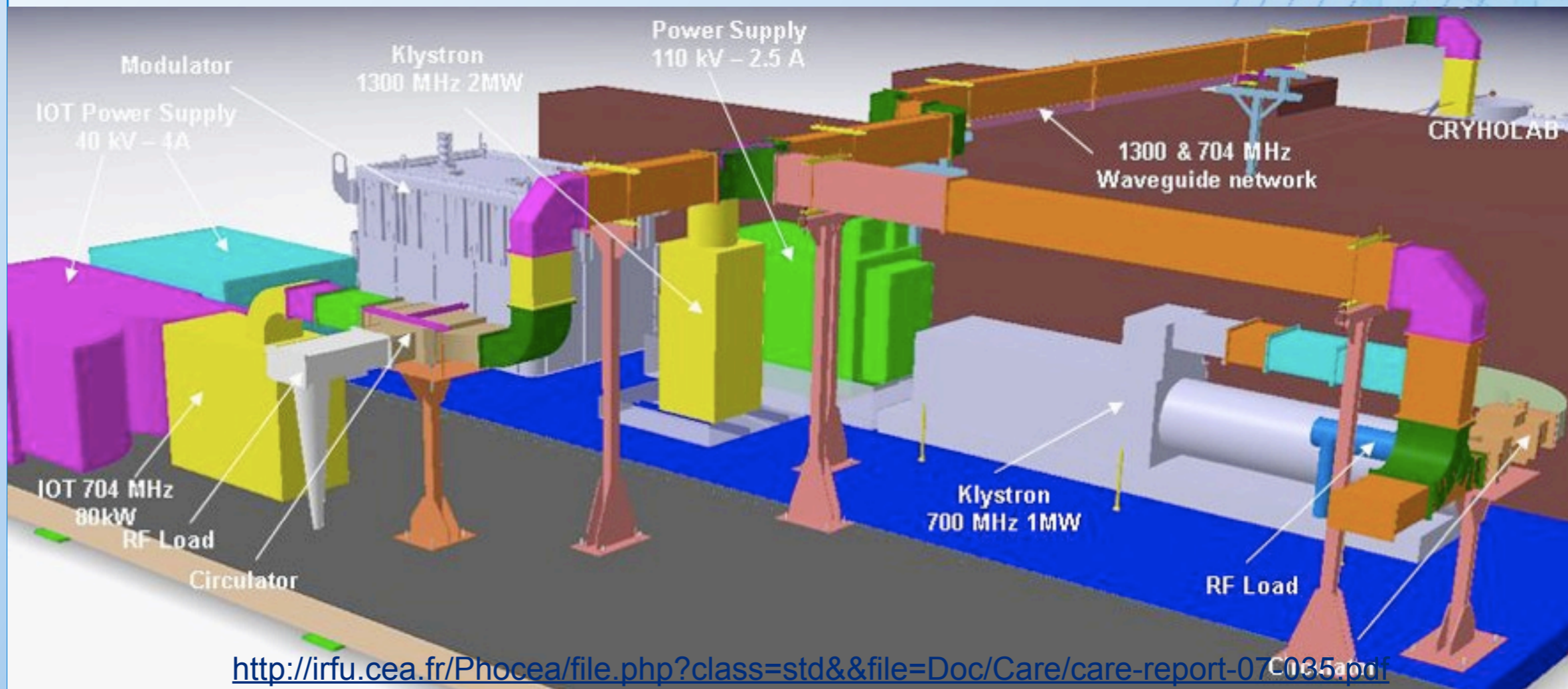


- ★ Simple design for reliability and cost reduction.
 - Not adjustable impedance antenna.
 - No mechanical movements allowed.
- ★ One coupler per cavity to avoid cross talk
- ★ Matched only when the cavity is fully loaded (beam and rf)
- ★ 704 MHz
- ★ Design power: 1.2 MW



TEST STAND AT CEA-SACLAY

- ★ 704 MHz, 1 MW vertical test stand for qualification of:
 - superconducting cavities
 - power couplers
 - tuning systems



CERN SM-18 TEST FACILITY

- ★ Discussions of joint prototype testing of a full high beta cryomodule for ESS and SPL by the end 2012.
 - 8 cavities for $\beta=0.92$
- ★ Further development for ESS is needed:
 - No real estate gradient crisis -- moderate requirement on gradients
 - On the other hand, very high power requirements



RF SYSTEMS

WP8



WORK UNITS

WP8

1. Coordination and communication
2. Low level RF system
3. RF power generation
4. RF power distribution
5. RF test facility

TEST FACILITY IN UPPSALA

- ★ Ongoing discussions for building a test facility for the rf source and distribution system with emphasis on
 - reliability
 - losses
 - power consumption
 - overall costs
- ★ Examples:
 - Development of klystron modulators with variable pulse length
 - Optimize droop compensation of modulator pulse
 - Optimize LLRF system in the spirit of mobile telephone r&d
 - Active amplifiers for vector modulators to splitting rf power to $\beta=0.65$ cavities

EXAMPLE: $\beta=0.92$ geometry

- ★ 1 MW at power coupler requires
 - 1.5 MW klystron (5% losses + 30% margin for LLRF)
 - 2.5 MW klystron modulator (62% klystron efficiency)

- ★ 13 MW power consumption averaged over year
 - 96 Klystrons, 85% modulator efficiency, 4.6 % duty cycle (2.3 ms pulses and 20 Hz repetition rate) and 4800 + 480 hour operation per year (including start up and r&d)

- ★ R&d on the rf systems is important
 - Increase reliability
 - Minimize beam losses
 - Reduce power consumption



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