ESS

Accelerator and target

Mats Lindroos on behalf of the ESS

PIP-II workshop / June 2014

A European research center

Copenhagen
Copenhagen-University
CPH Airport

Bridge
SE-DK

MEDICON VILLAGE

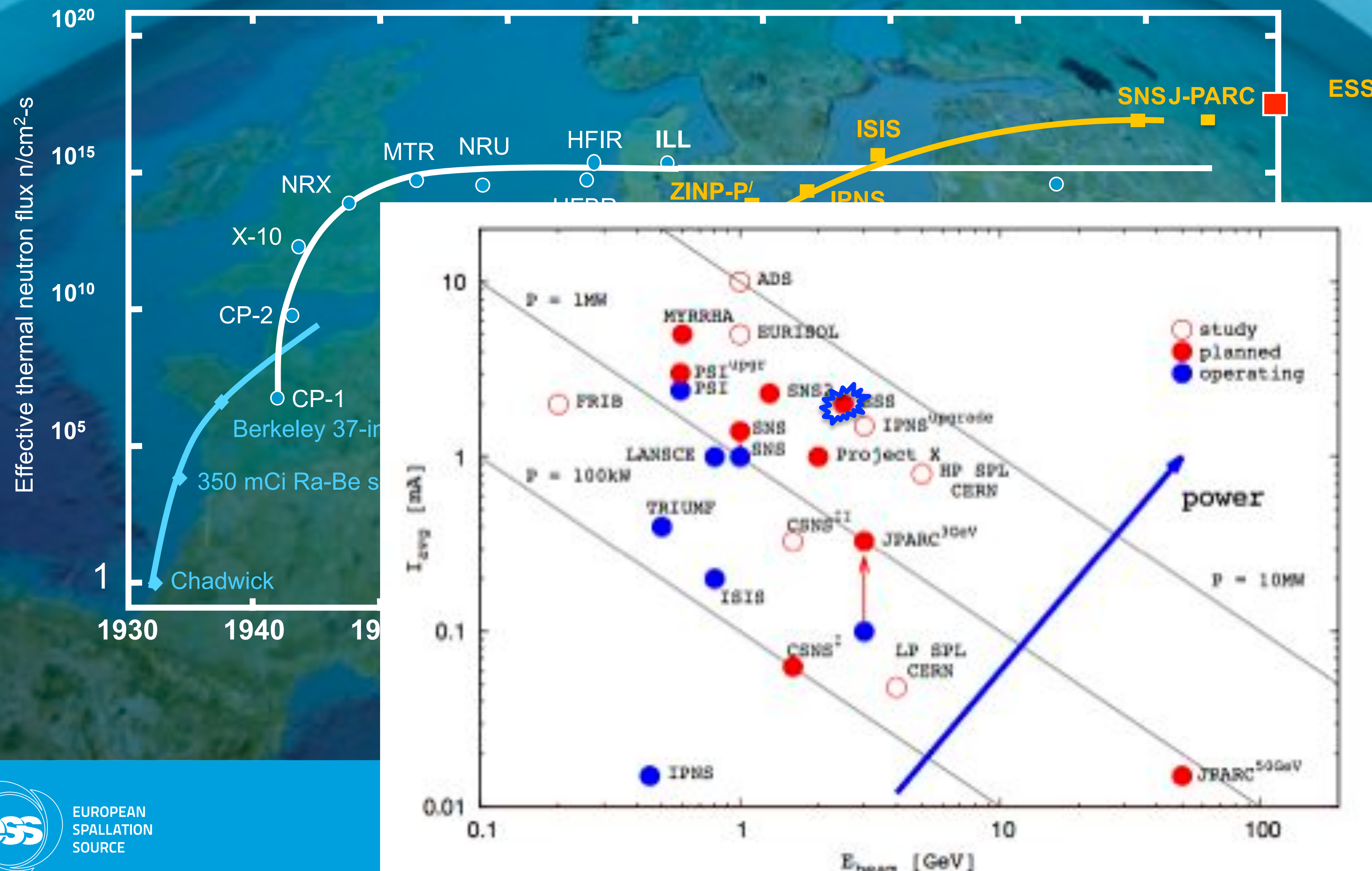
IDEON
Innovation
Environment
Incubators
Venture Capital
Marketing Advice

SCIENCE VILLAGE SCANDINAVIA

Neutron
Source

EUROPEAN SPALLATION SOURCE

ESS - Bridging the neutron gap



EUROPEAN
SPALLATION
SOURCE

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

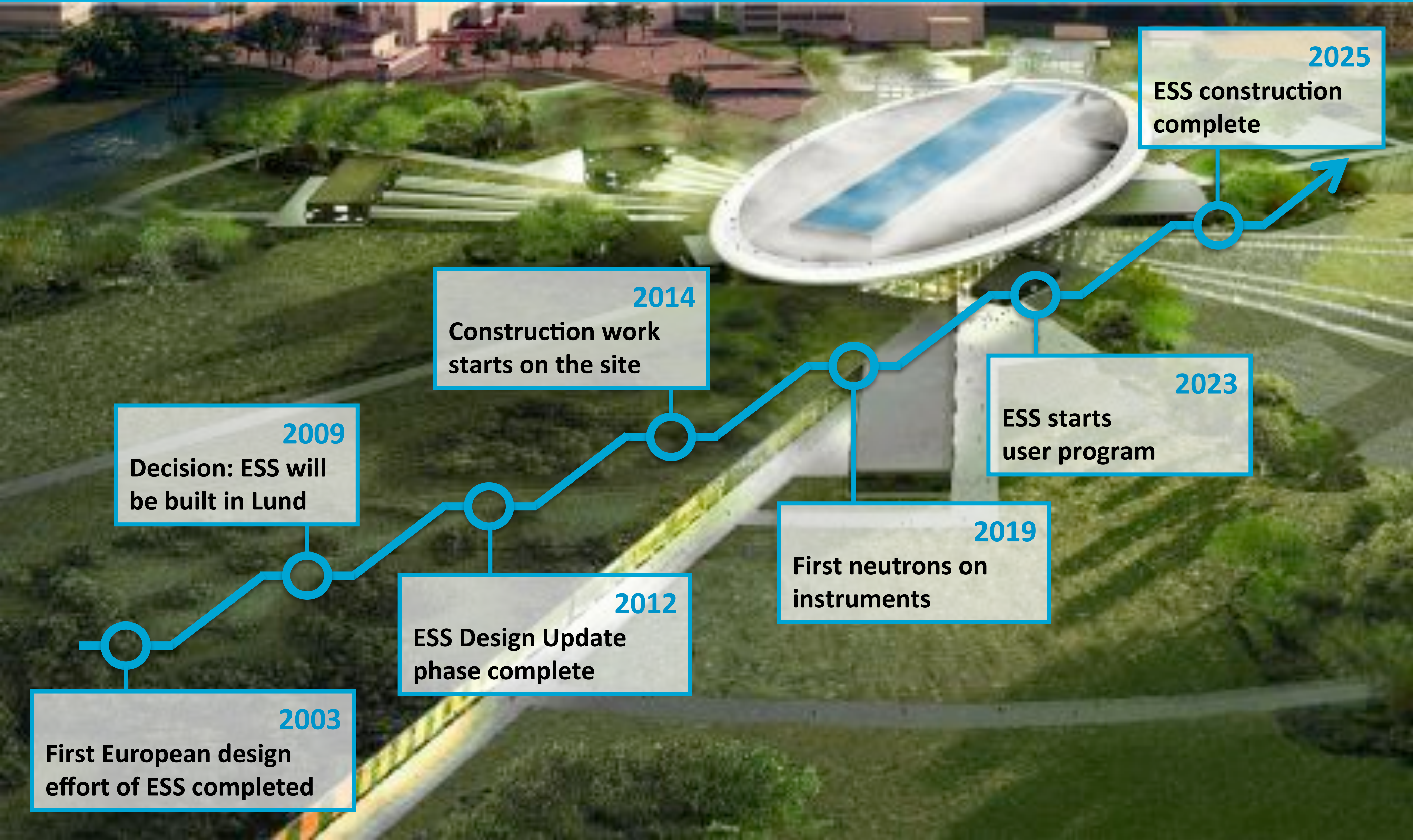
Construction cost: 1843 M€
Operation cost: 140 M€
Decommissioning cost: 177 M€

ESS AB 2014, ca 250 personer, 32 nationaliteter

EUROPEAN SPALLATION SOURCE

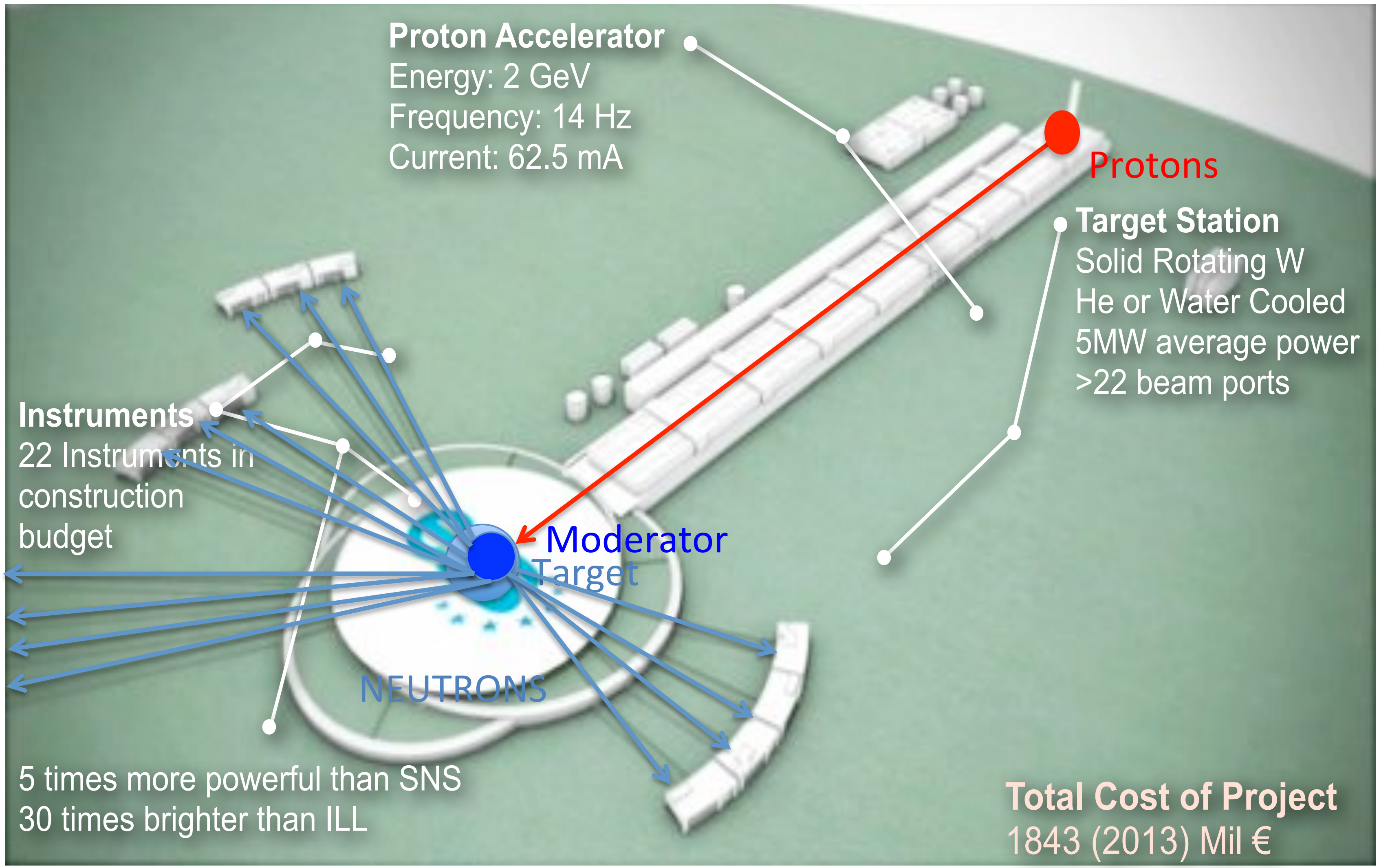
Road to realizing the world's leading facility for research using neutrons

EUROPEAN SPALLATION SOURCE



Helicopter view of ESS

EUROPEAN SPALLATION SOURCE



Build and operate a 5 MW SCRF linac

Design Drivers:

High Average Beam Power

5 MW

High Peak Beam Power

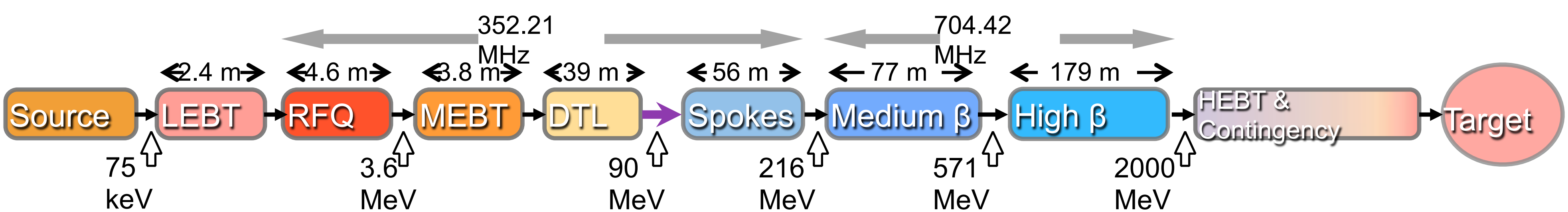
125 MW

High Availability

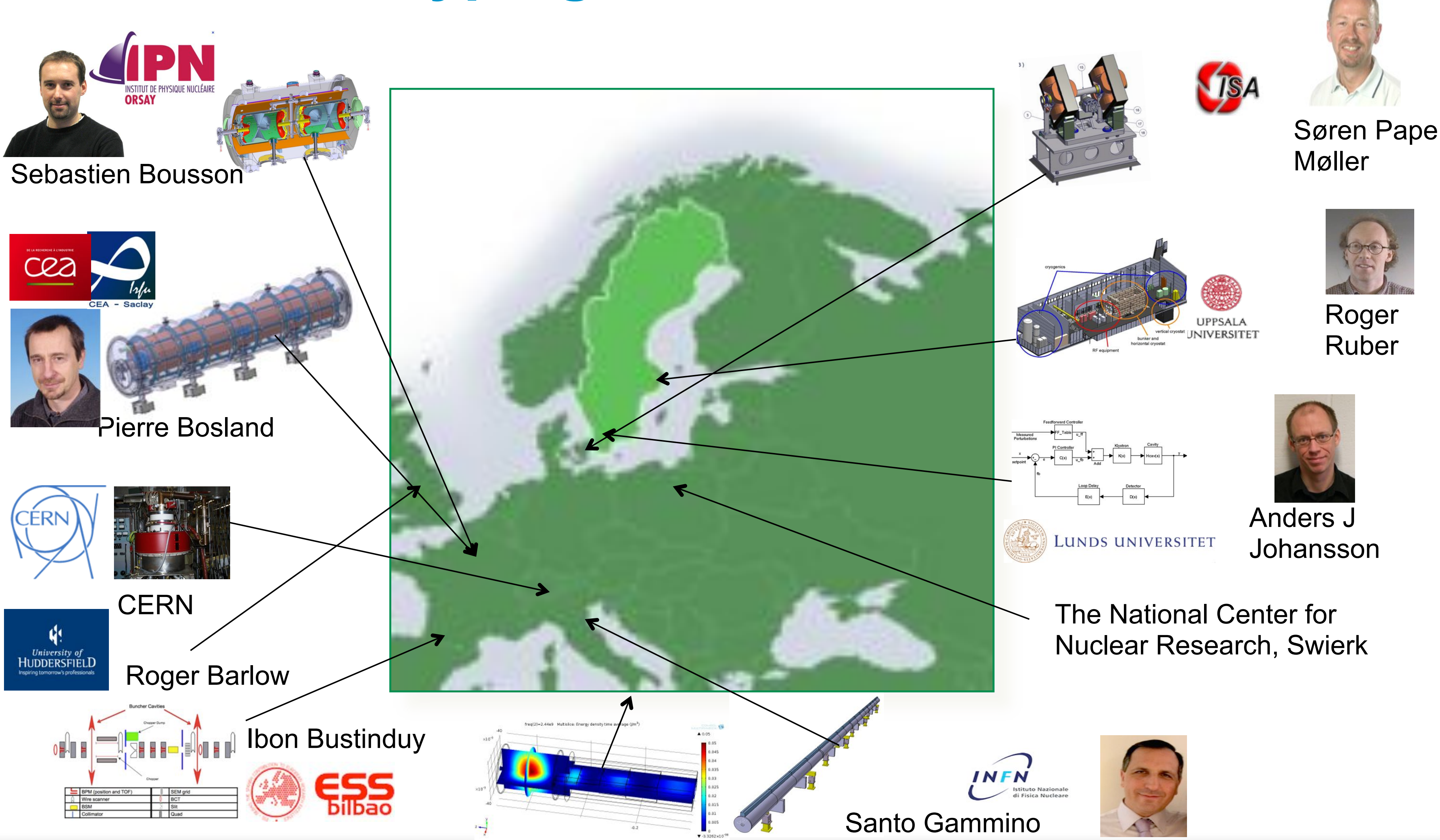
> 95%

Key parameters:

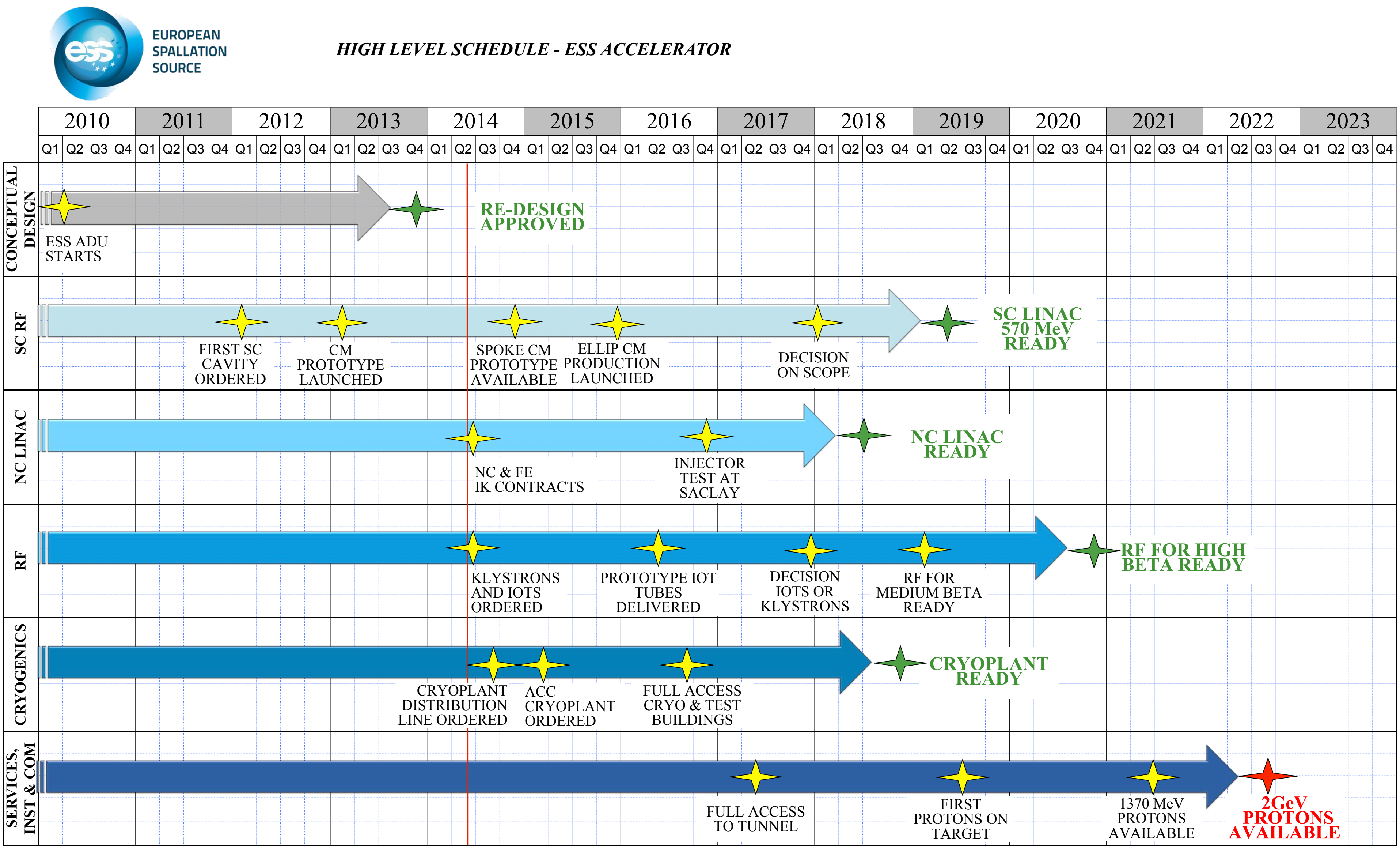
- -2.86 ms pulses
- -2 GeV
- -62.5 mA peak
- -14 Hz
- -Protons (H+)
- -Low losses
- -Minimize energy use
- -Flexible design for future upgrades



Prototyping the ESS accelerator



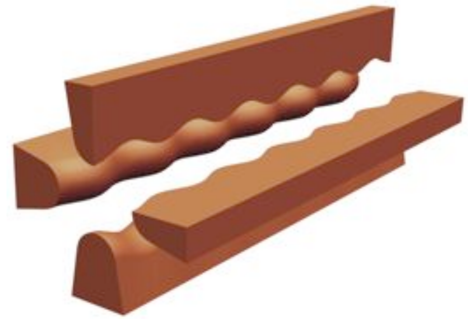
Plans



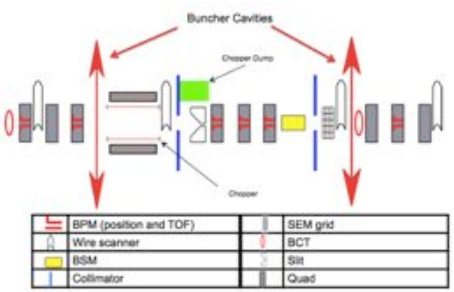
EUROPEAN SPALLATION SOURCE
HIGH LEVEL SCHEDULE - ESS ACCELERATOR
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
Q1 Q2 Q3 Q4
CONCEPTUAL DESIGN
ESS ADU STARTS
RE-DESIGN APPROVED
SC RF
FIRST SC CAVITY ORDERED
CM PROTOTYPE LAUNCHED
SPOKE CM PROTOTYPE AVAILABLE
ELLIP CM PRODUCTION LAUNCHED
DECISION ON SCOPE
SC LINAC 570 MeV READY
NC LINAC
NC & FE IK CONTRACTS
INJECTOR TEST AT SACLAY
NC LINAC READY
RF
KLYSTRONS AND IOTS ORDERED
PROTOTYPE IOT TUBES DELIVERED
DECISION IOTS OR KLYSTRONS
RF FOR MEDIUM BETA READY
RF FOR HIGH BETA READY
CRYOGENICS
CRYOPLANT DISTRIBUTION LINE ORDERED
ACC CRYOPLANT ORDERED
FULL ACCESS CRYO & TEST BUILDINGS
CRYOPLANT READY
SERVICES, INST & COM
FULL ACCESS TO TUNNEL
FIRST PROTONS ON TARGET
1370 MeV PROTONS AVAILABLE
2GeV PROTONS AVAILABLE

Ion Source and Normal-Conducting Linac

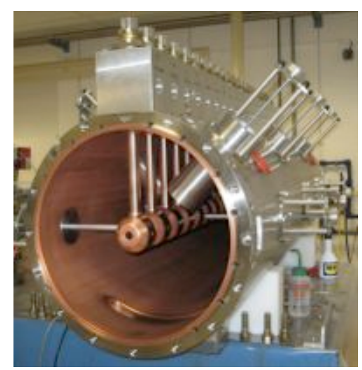
Prototype proton source operational, and under further development, in Catania. Output energy 75 keV.



Design exists for ESS RFQ similar to 5 m long IPHI RFQ at Saclay. Energy 75 keV->3.6 MeV.



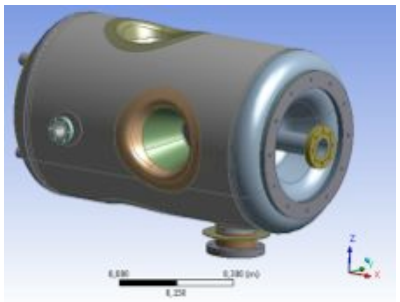
Design work at ESS Bilbao for MEBT with instrumentation, chopping and collimation.



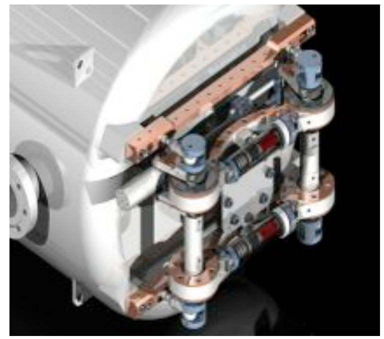
DTL design work at ESS and in Legnaro, 3.6 ->90 MeV.

Picture from CERN Linac4 DTL.

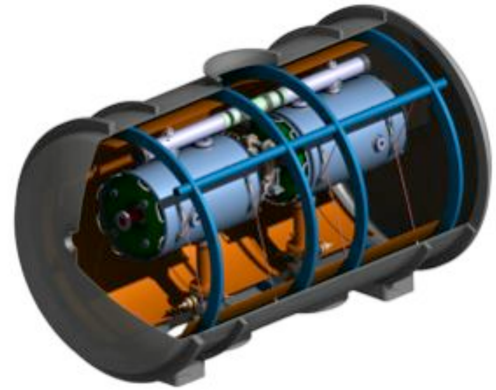
Spoke Cavities and Cryomodules



Superconducting double-spoke accelerating cavity, for particles with beta = 0.5, energy 90->216 MeV.



Cold tuner, to mechanically fine-tune the 352 MHz resonance frequency.



Cryomodule, holding two cavities at 2 K with superfluid helium. Length 2.9 m, diameter 1.3 m.

Power coupler, the antenna feeding up to 300 kW RF power to the cavities.

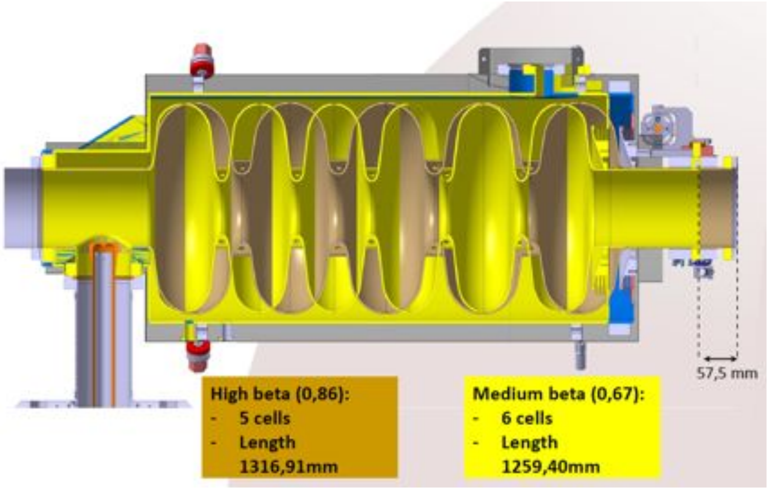
Single-spoke prototype for EURISOL

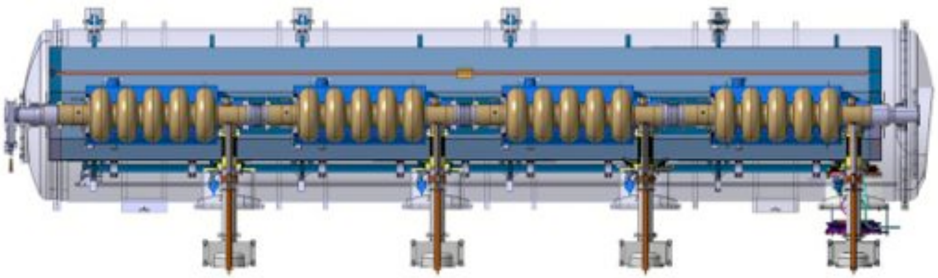
Cavity design done at IPN, Orsay, and prototype cavity has been ordered. Niobium procured and sent to manufacturer.

Cryomodule design highly advanced but not complete.

Elliptical Cavities and Cryomodules

Superconducting five-cell elliptical cavity (not ESS). Two families, for beta = 0.67, energy 216->561 MeV and beta = 0.86, energy 561->2000 MeV.





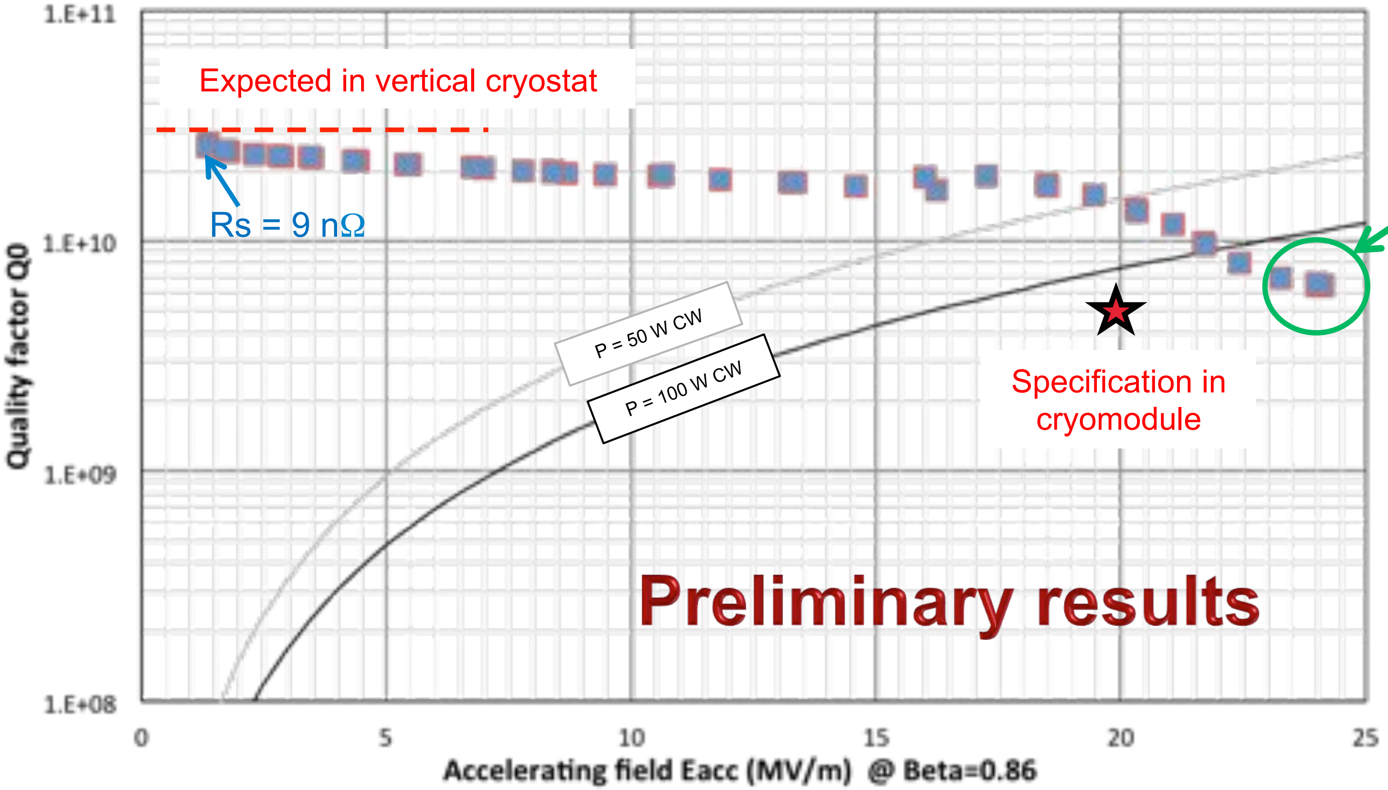
ESS elliptical cryomodule (not final) with 4 5-cell cavities and 4 power couplers for up to ~1 MW peak RF power.

Cavity and cryomodule design well advanced at Saclay.

Elliptical Cavities Cryomodule Technology Demonstrator, ECCTD, to be ready 2015.

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) : $Q_i = 6.5^e9 \pm 1^e9$, $Q_t = 6.8^e12$
- 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

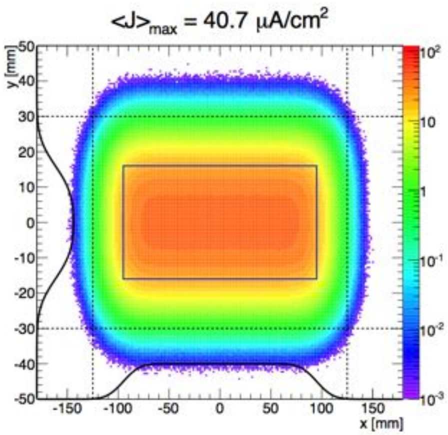
☞ No quench observed

Next plans:

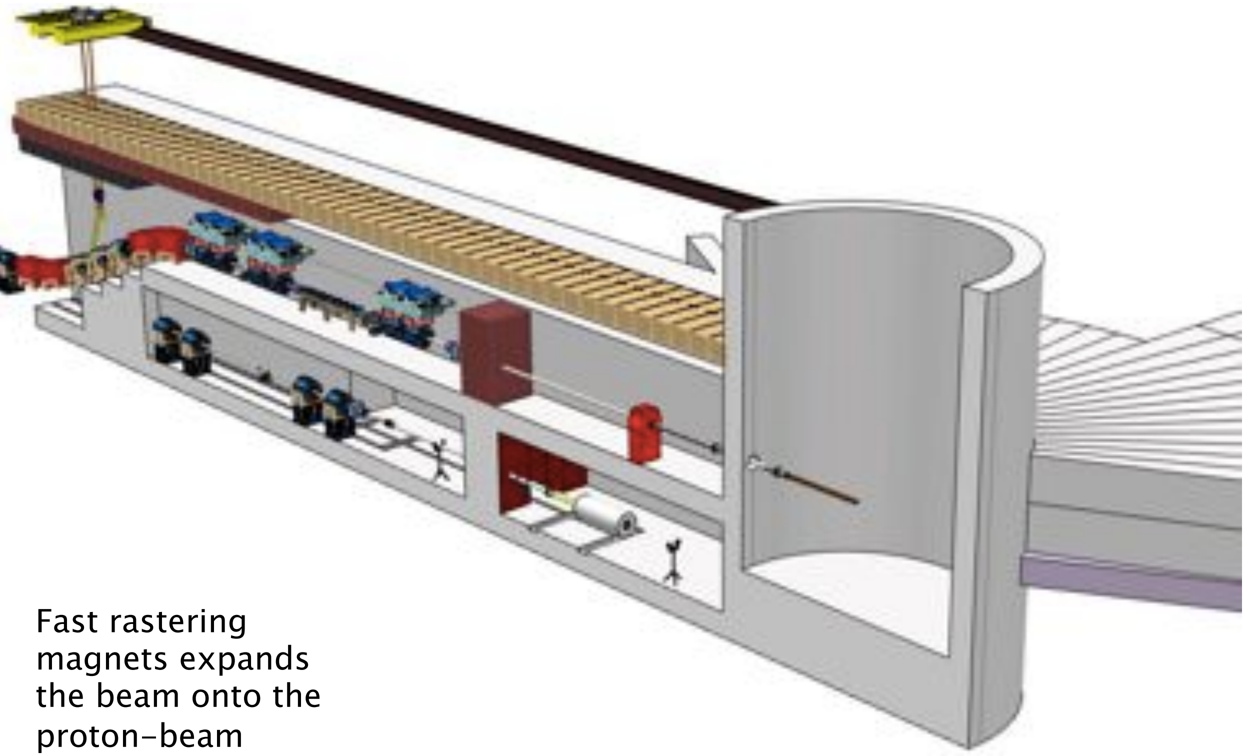
- Measurement of resonant frequency of 1st bandpass mode at 2K
- Measurement of resonant frequency of HOM at 2K
- If possible, increase accelerating field up to the quench limit
- Perform heat treatment at CERN at 650°C under vacuum

High-Energy Beam Transport

Quadrupole doublet for linac and HEBT



Fast rastering magnets expands the beam onto the proton-beam window and the 250 mm × 60 mm beam entrance window on the target wheel



The HEBT design is a contribution from ISA, Århus.

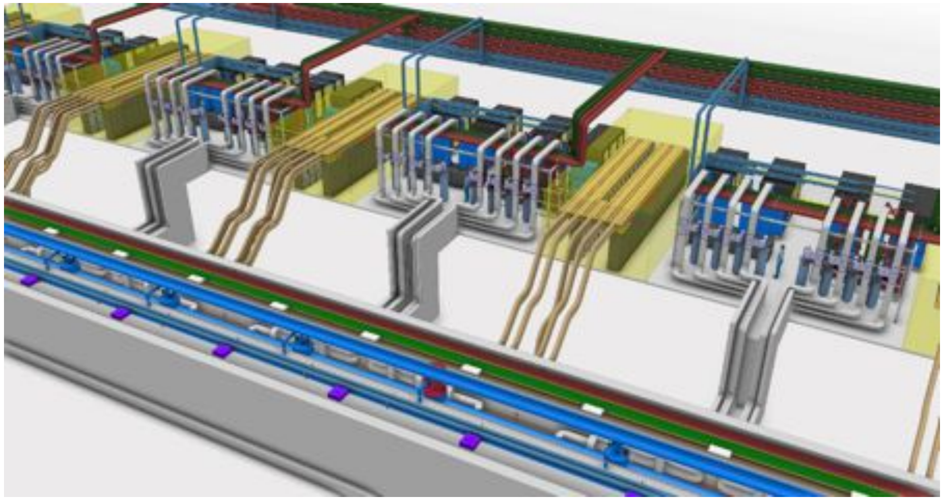
RF Systems

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

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



Layout of ESS linac tunnel and klystron gallery

Cryogenics

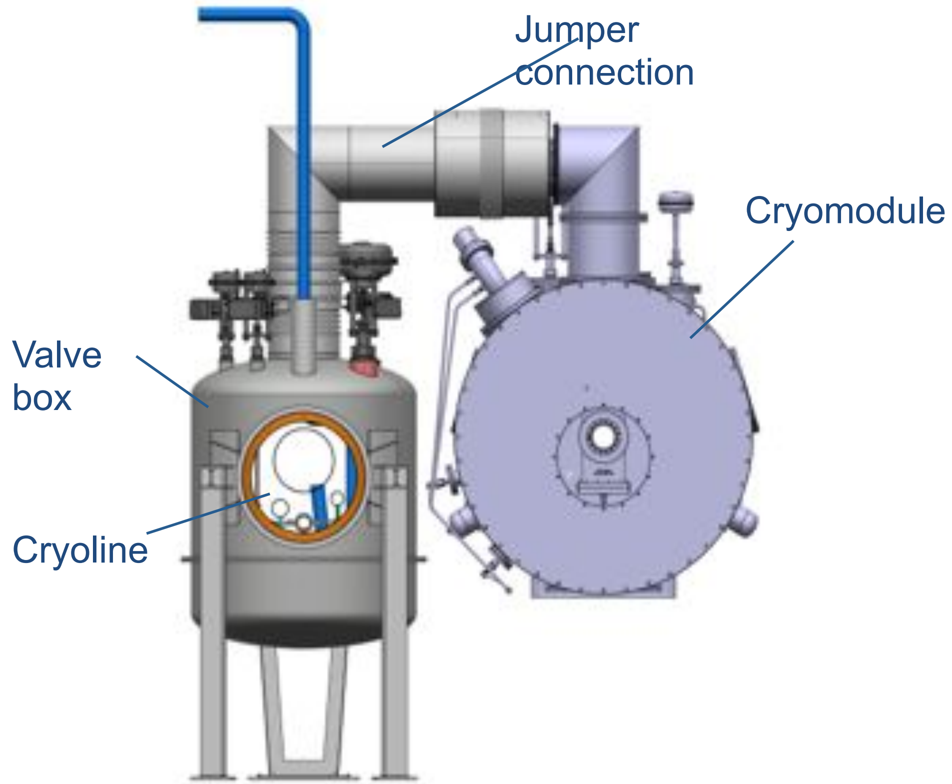
Three cryogenic plants

- Accelerator: 3.1 kW @ 2K, 12.8 kW @40 – 50 K plus 8 g/s helium liquefaction
- Target: ~ 20 kW @ 16K
- Test & Instruments ~ 250 W@ 4.5 K and 200 W @ 40K

Distribution system

- Permits independent cool down & warm up of cryomodules, likely IKC

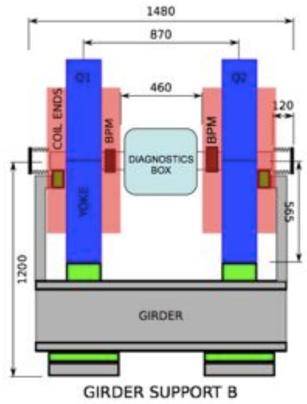
Cryoplant orders to be placed in 2015 with operations starting in 2017 – 2018



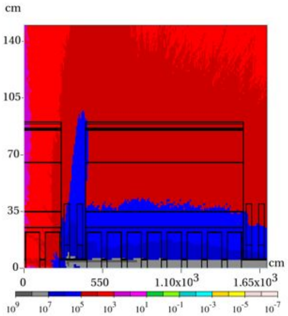
Further Components and Challenges…

… not mentioned for lack of time

- *Beam instrumentation*
- Control system (ICS)
- Machine protection
- *Personnel protection*
- Vacuum
- *Test stands*
- Cooling, electricity
- Installation
- Logistics
- Safety
- Reliability
- System engineering
- In-kind
- Time schedule
- Budget

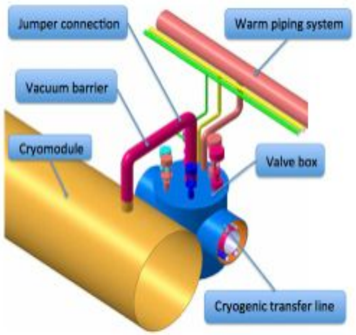


Quadrupole doublet on girder with BPMs and diagnostics box

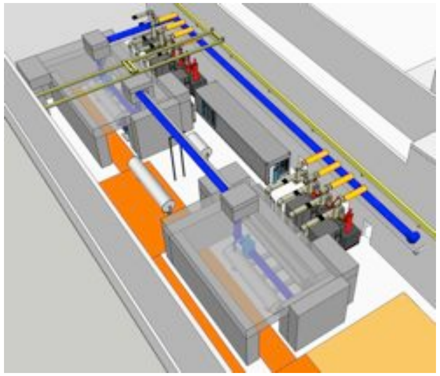


Beam-loss simulations

Control-box prototype

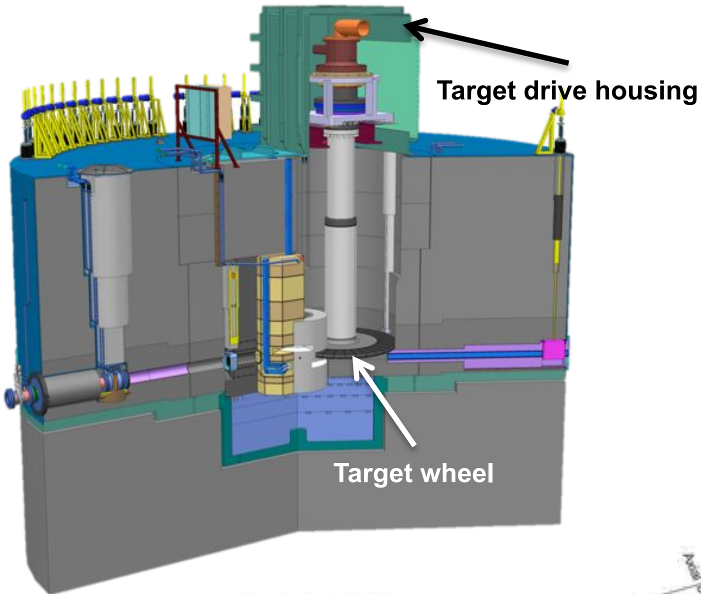


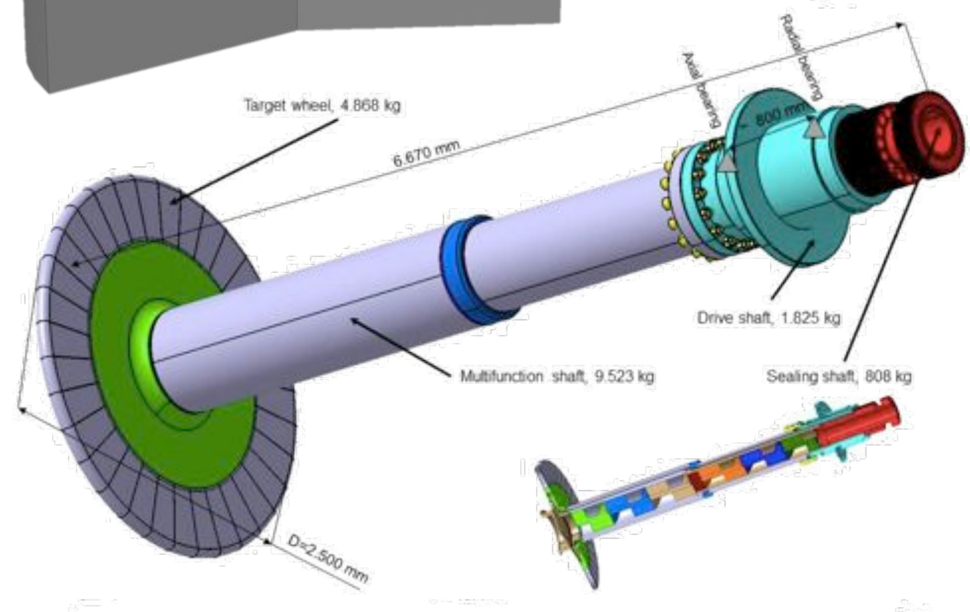
Cryogenic distribution



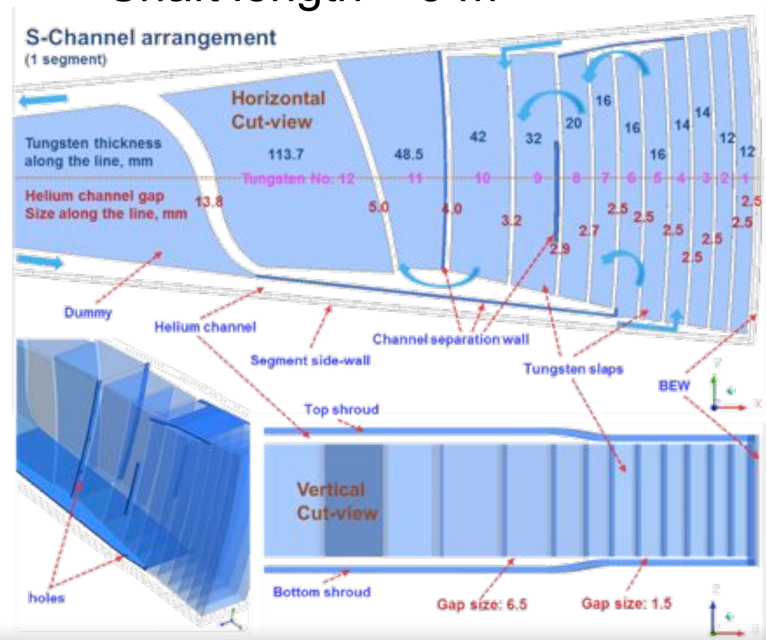
Cryomodule test stand

Target Wheel

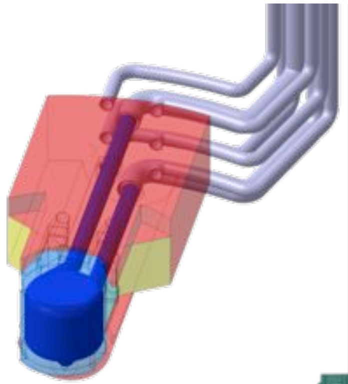


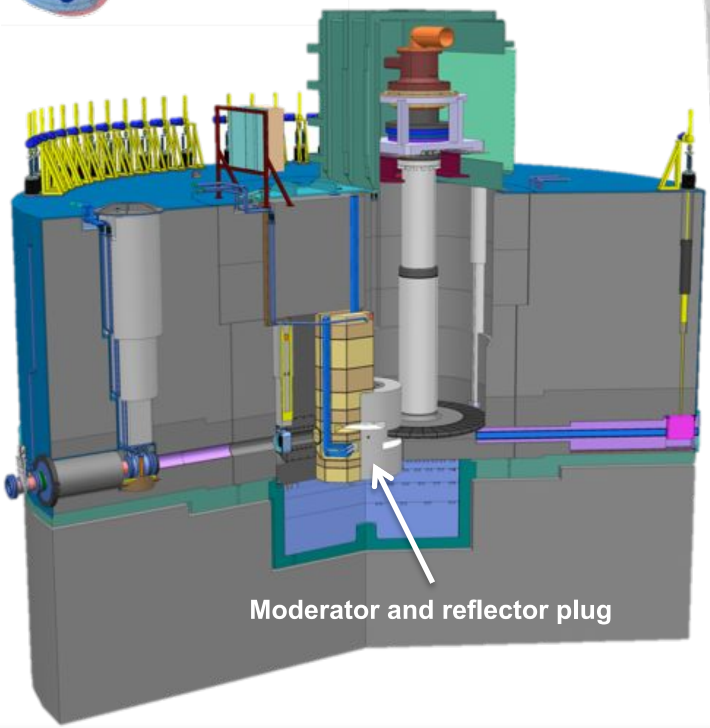


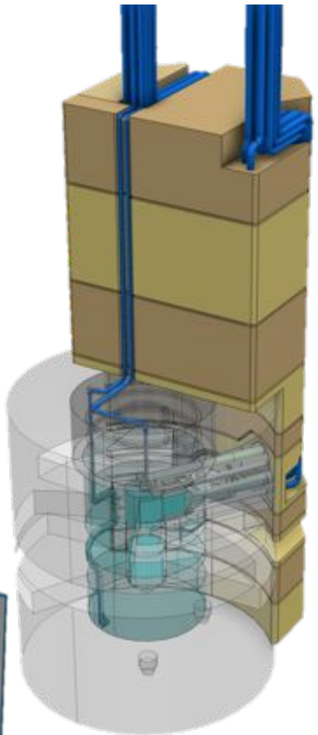
- Tungsten slabs in 33 sectors
- Helium coolant
  - Mass flow 3 kg/s
  - Pressure 0,3 Mpa
  - Inlet temperature 20 °C
  - Outlet temperature 220 °C
- Rotational speed 25,5 rpm
- Wheel diameter 2,5 m
- Shaft length > 5 m



Moderators and Reflectors



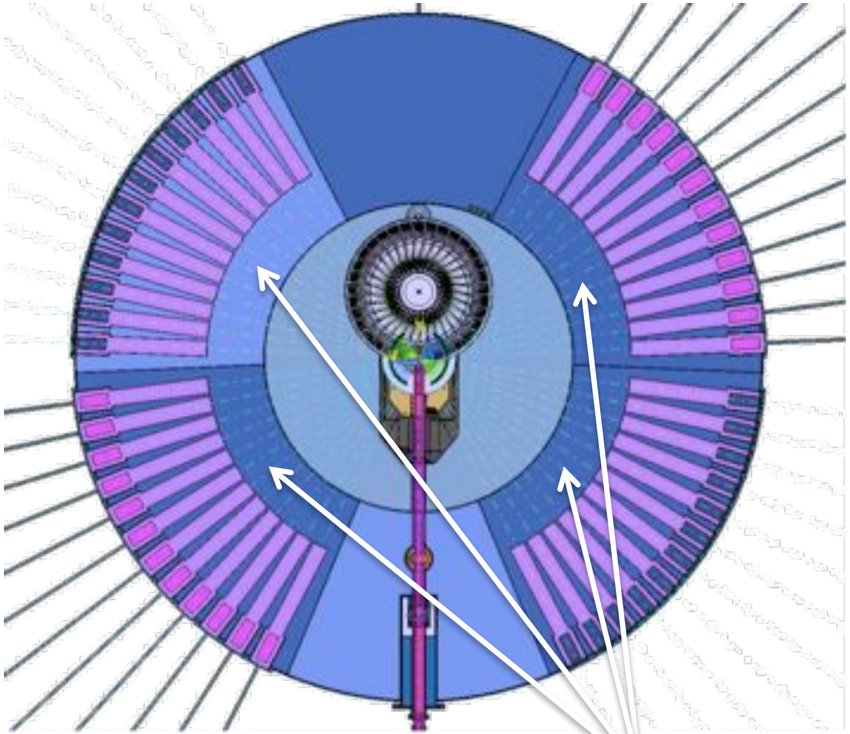


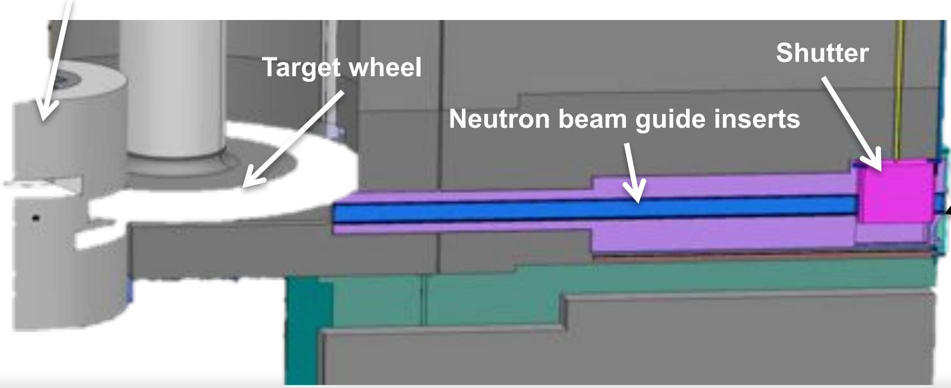


- Cold moderators
  - Super-critical hydrogen at 20 K and 1.5 MPa
  - Vessel in aluminium alloy
- Water moderator assemblies
  - Vacuum jacket
  - Thermal water
  - Pre-moderator surrounding the cold moderator vessel
  - Extended wings to facilitate thermal or bi-spectral beam extraction
- Inner reflector
  - Beryllium
  - Complex “cylindrical” aluminium vessel
  - Water cooled
- Outer reflector
  - Steel
  - Water cooled
- Cut-outs
  - for the view path to the beam extraction
  - for the wheel

Neutron Beam Extraction

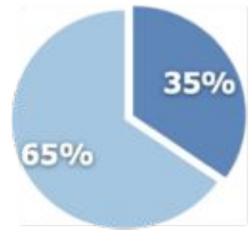
- Neutron beam extraction system design
  - Four 60 degree sectors, whereof
    - Two sectors view the upper moderators
    - Two sectors view the lower moderators
  - In total 48 ports for potential neutron beam line location
  - Neutron beam guide inserts can be located as close as 2 m from the surfaces 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

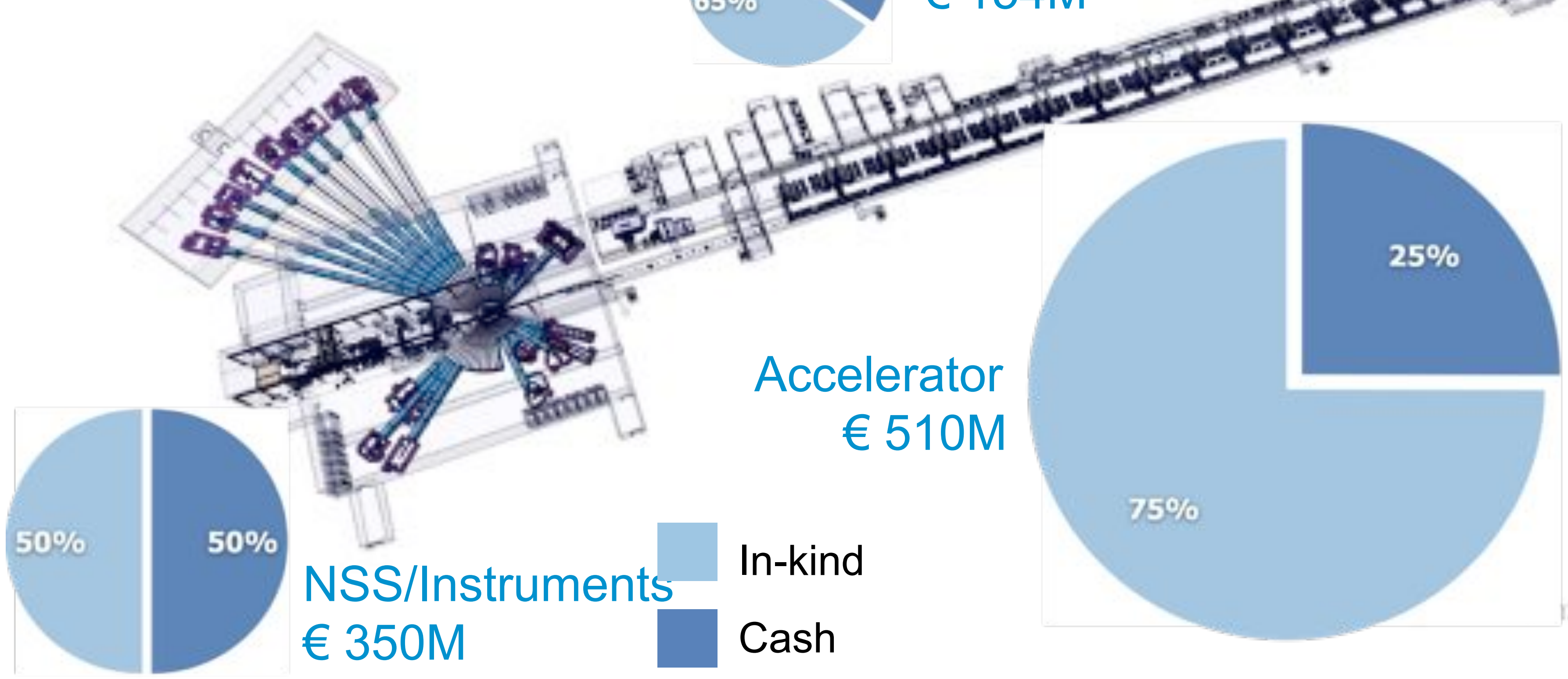




ESS In-kind contributions potential

Total construction cost:
€ 1,84 billion

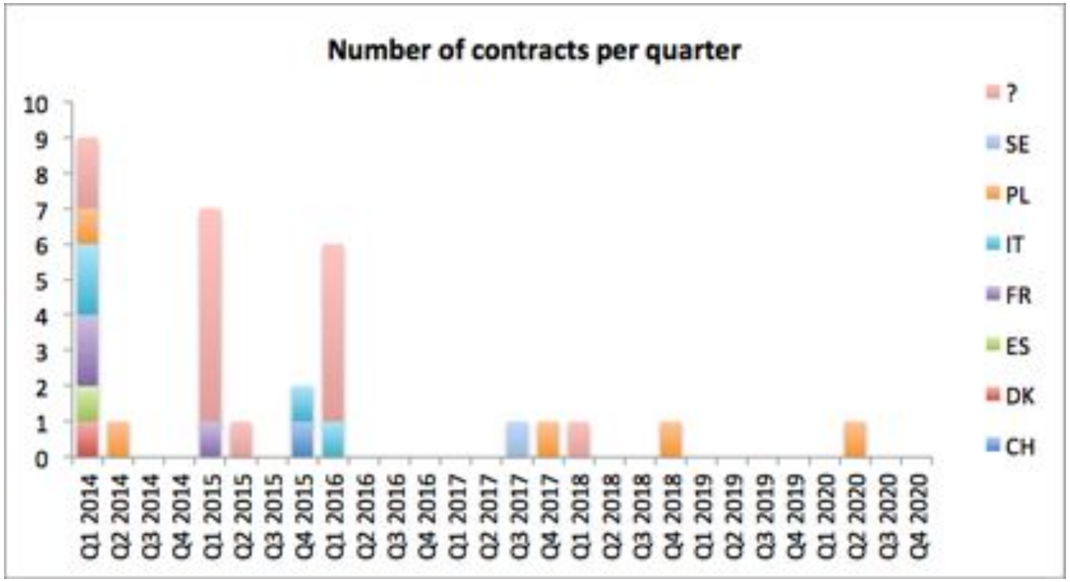


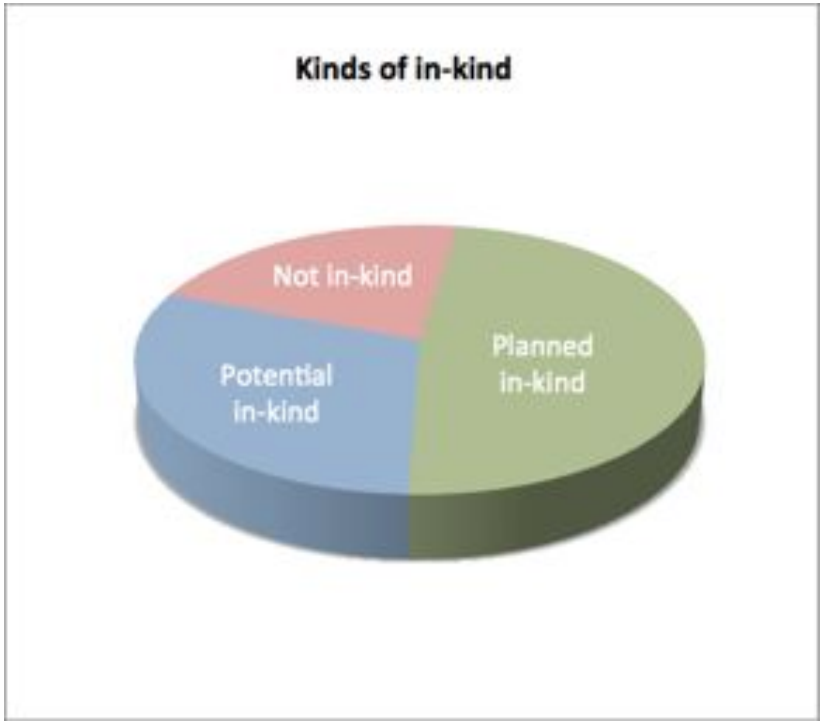


Collaborative projects

- ESS is an emerging research laboratory with (still) very limited capacity in-house
- Two possibilities:
  - Limit the scope of the project so that it can be done with in-house resources
  - Work in a collaboration where the scope of the project can be set by the total capacity (distributed) of the partners
- The accelerator part of the project well suited for this as this community has a strong tradition of open collaboration
- To keep cost down and to optimize schedule this requires that investments in required infrastructure is done at the partner with best capacity to deliver

ACCSYS update in-kind discussions

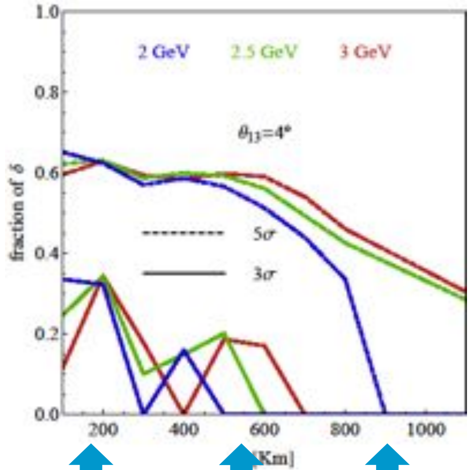




- Potential partners identified for 60% of the total planned/potential in-kind value
- Planned/potential in-kind is 78% of accelerator budget
- Many activities start Q1 2014, reflecting the importance of reaching agreements soon

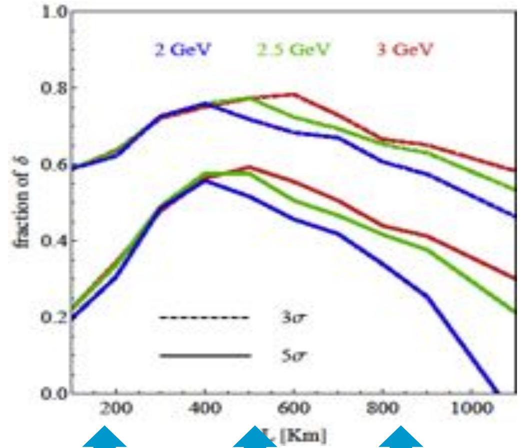
ESSnuSB

Before spring 2012 $\Theta_{13}=4^{\circ}$

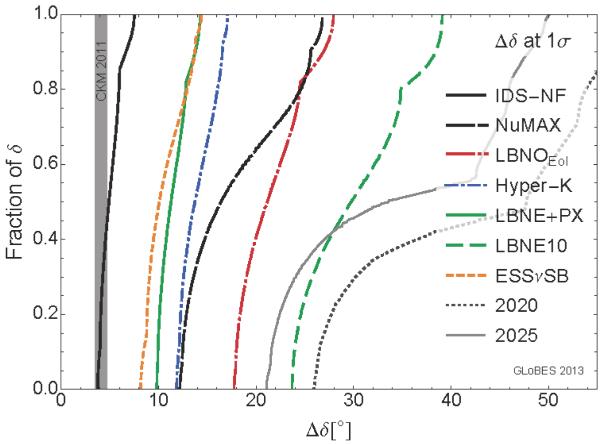


1st osc. max 2nd osc. max 3rd osc. max

After spring 2012 $\Theta_{13}=8.73^{\circ}$



1st osc. max 2nd osc. max 3rd osc. max



- New accumulation ring with staggered beam extraction using solid state switch driven ILC like strip line kickers of up to 100 pulses to match pulse length to moderators and simplify target design
- Linac operated with H- and at 28 Hz to keep both target station operating at 5 MW
- Support from ESS for Design study proposal

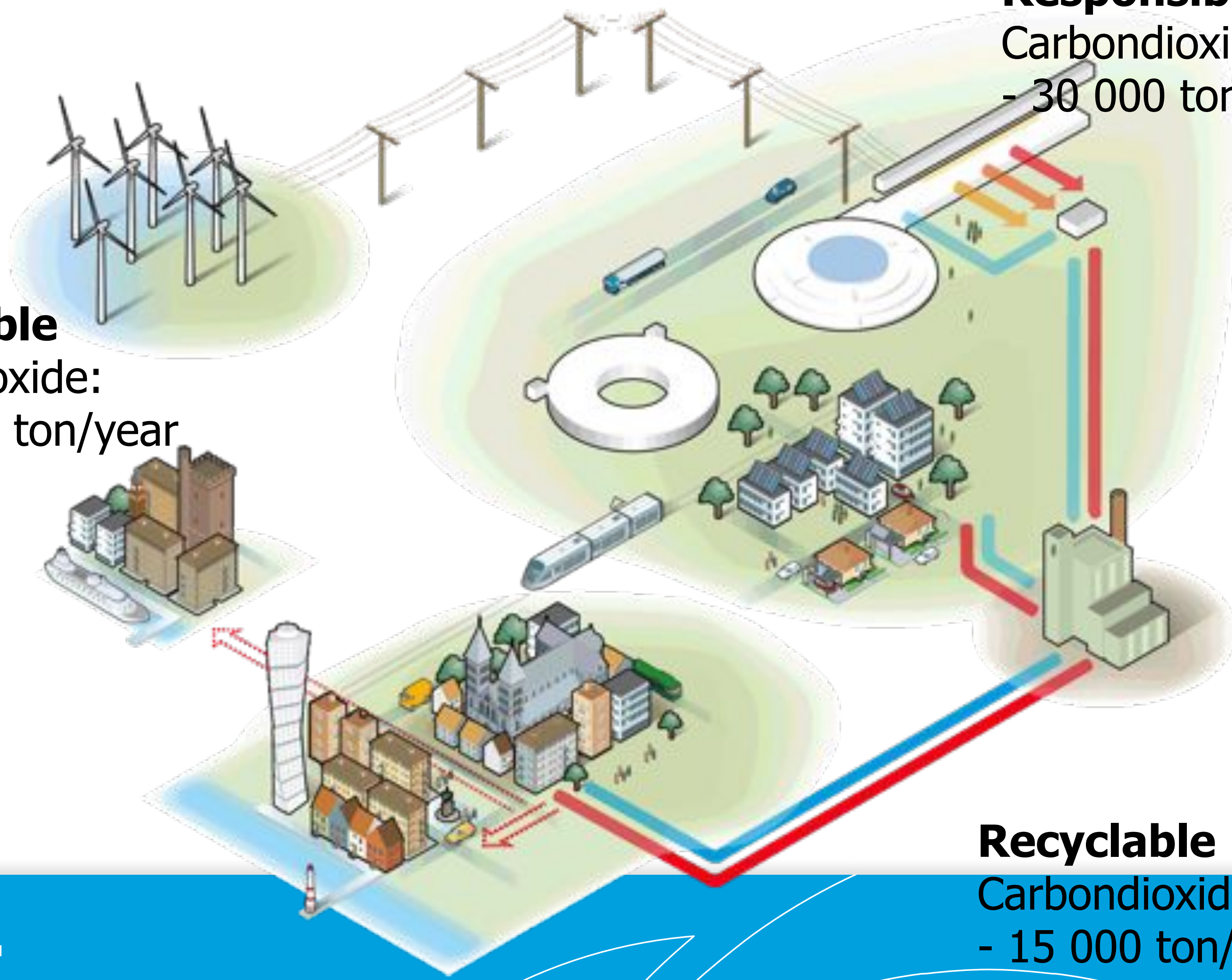
Neutron - antiNeutron oscillations

- Provided new physics occurs beyond the Standard Model at the mass scale of the order of 10^2 to 10^3 TeV the oscillation time could be in the region of 10^8 s
- The experimental search for neutron-antineutron oscillations was done at the ILL high flux reactor at Grenoble (1994). A neutron beam of intensity 10^{11} n/s was propagated for a time t~-0.1 s in vacuum in a region shielded against the external magnetic field. No antineutron was detected in $2.4.10^7$ s running time.
- ESS can probably do more than two orders of magnitude better

A sustainable research facility

Responsible
Carbondioxide:
- 30 000 ton/year

Renewable
Carbondioxide:
- 120 000 ton/year

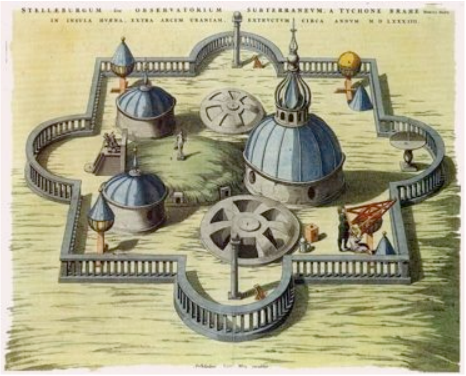


Recyclable
Carbondioxide:
- 15 000 ton/year

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

In modern time, definitely YES !

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



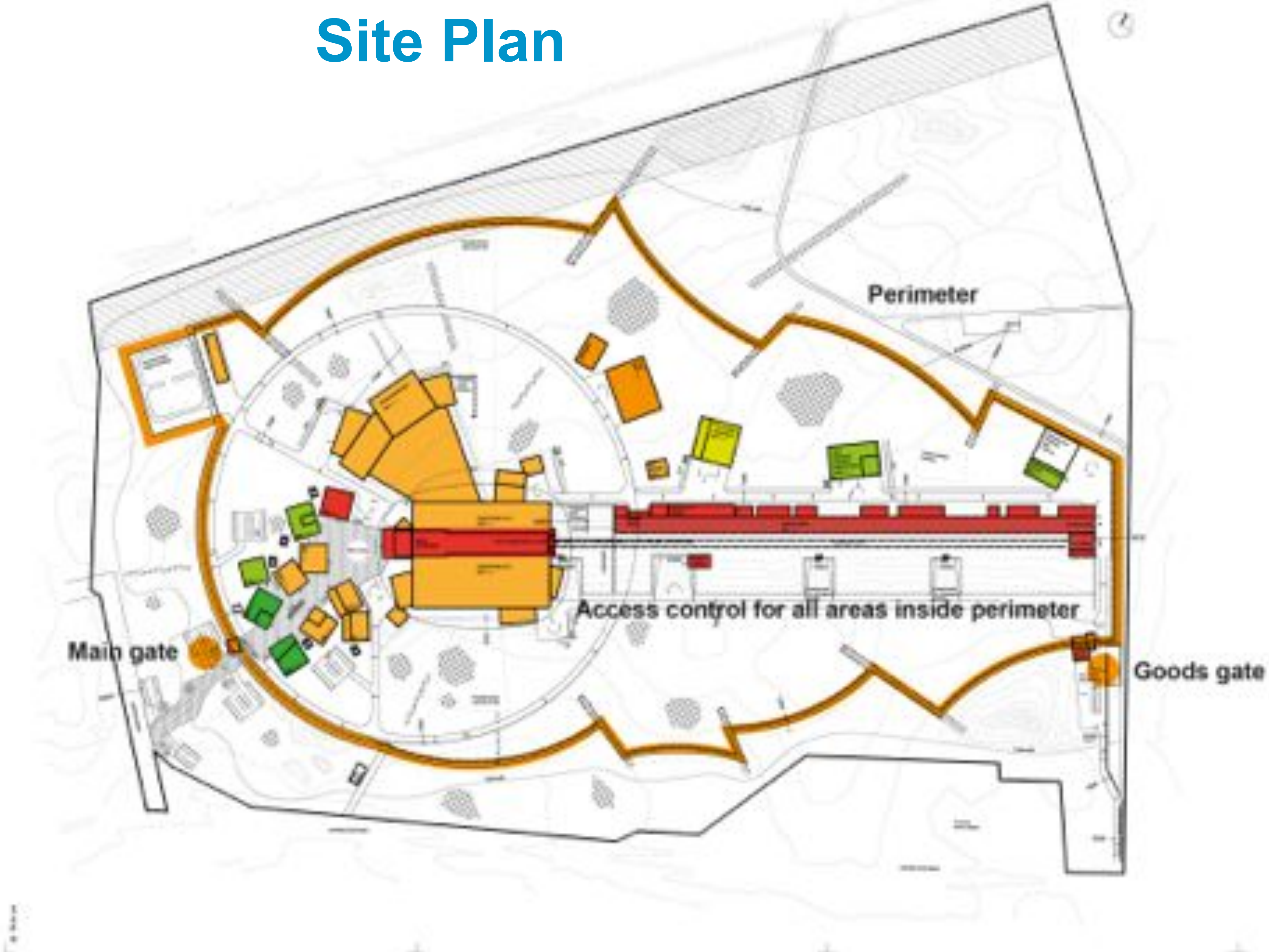
"With better measurements of the stars positions and movements I can make much better horoscopes for you, your majesty!"

EUROPEAN SPALLATION SOURCE

EUROPEAN SPALLATION SOURCE

Welcome

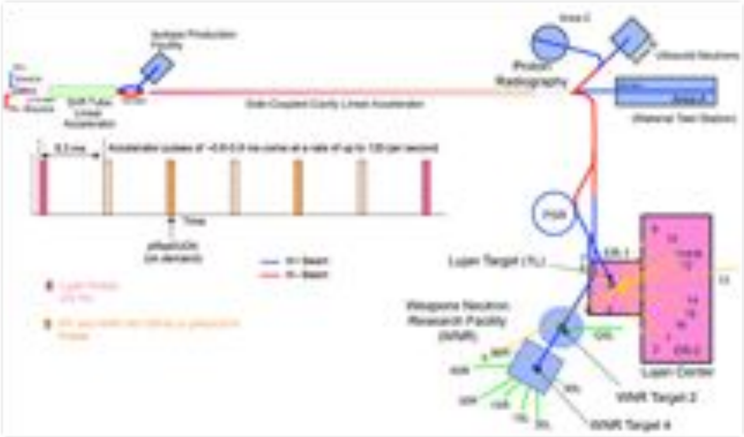
Site Plan


Perimeter
Access control for all areas inside perimeter
Main gate
Goods gate

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

Short pulse sources-LANCSE

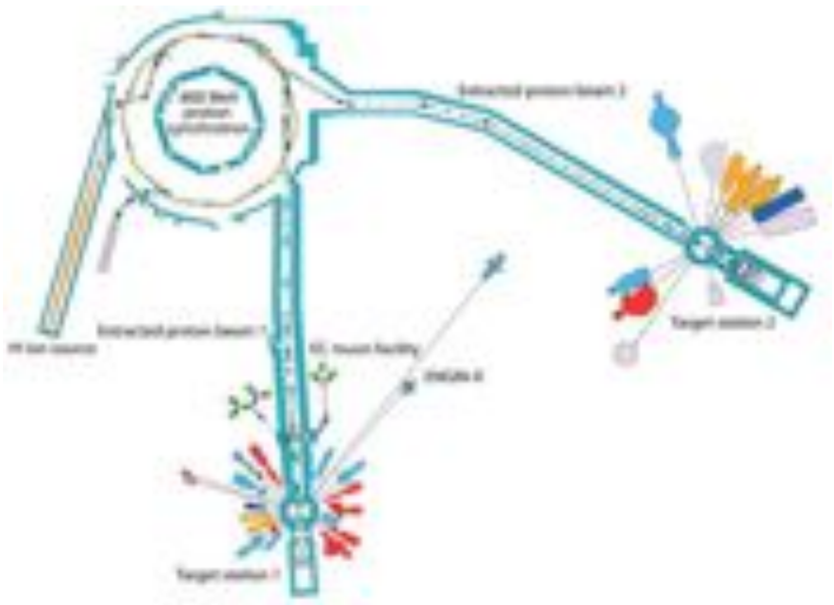


- LANCSE, NC LINAC /Storage ring, 1972, 100 kW, 800 MeV, 17 mA in linac, 600 ns, 20 Hz
- Examples: Combined H- and H+ acceleration

Accelerated intensity at 800 MeV:

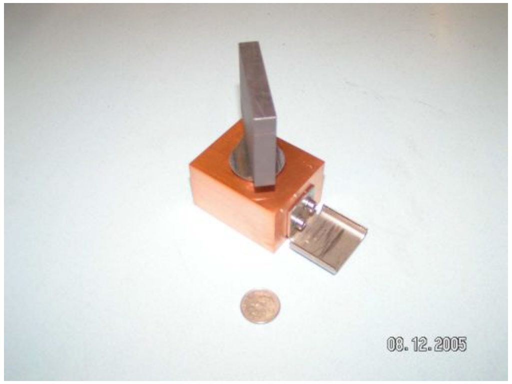
2.5x10^{13} ppp - 3.75x10^{13} ppp

(200 μA) (300 μA)

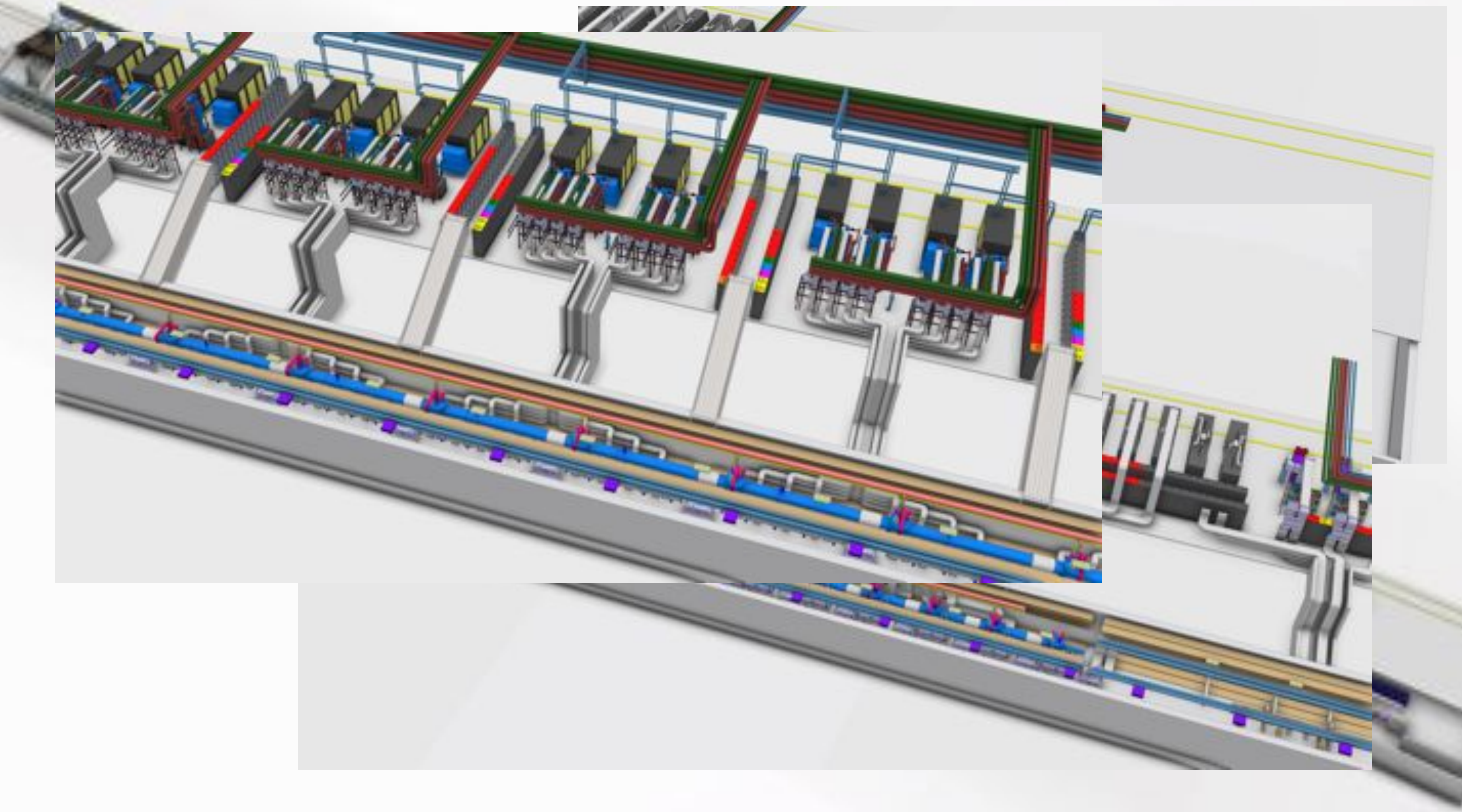


- Neutron scattering facility
- Two target stations
- Muon facility

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

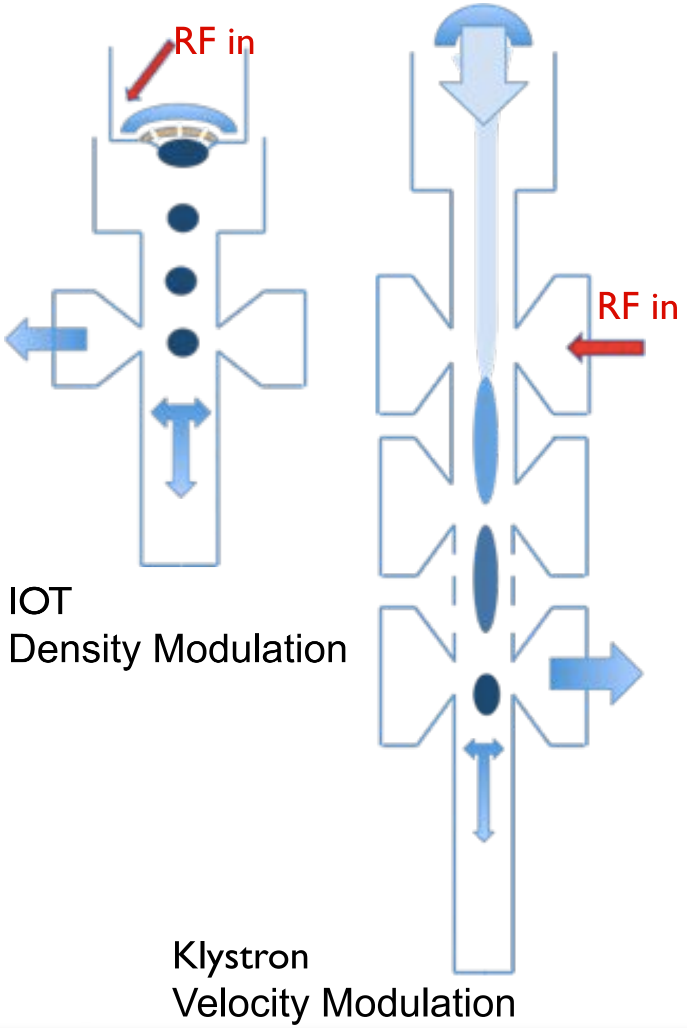


Linac layout



Inductive Output Tubes or klystrons?

- ESS
  - Induction Output Tubes, IOTs
    - Higher electrical efficiency
      - They don't conduct in the absence of input drive
    - Compact
    - Short MTTR
    - Cheaper modulator (No high voltage switching)
  - Why suddenly IOTs?
    - Development of Pyrolytic graphite grids
    - Solid state drivers



Courtesy of Morten Jensen (ESS)

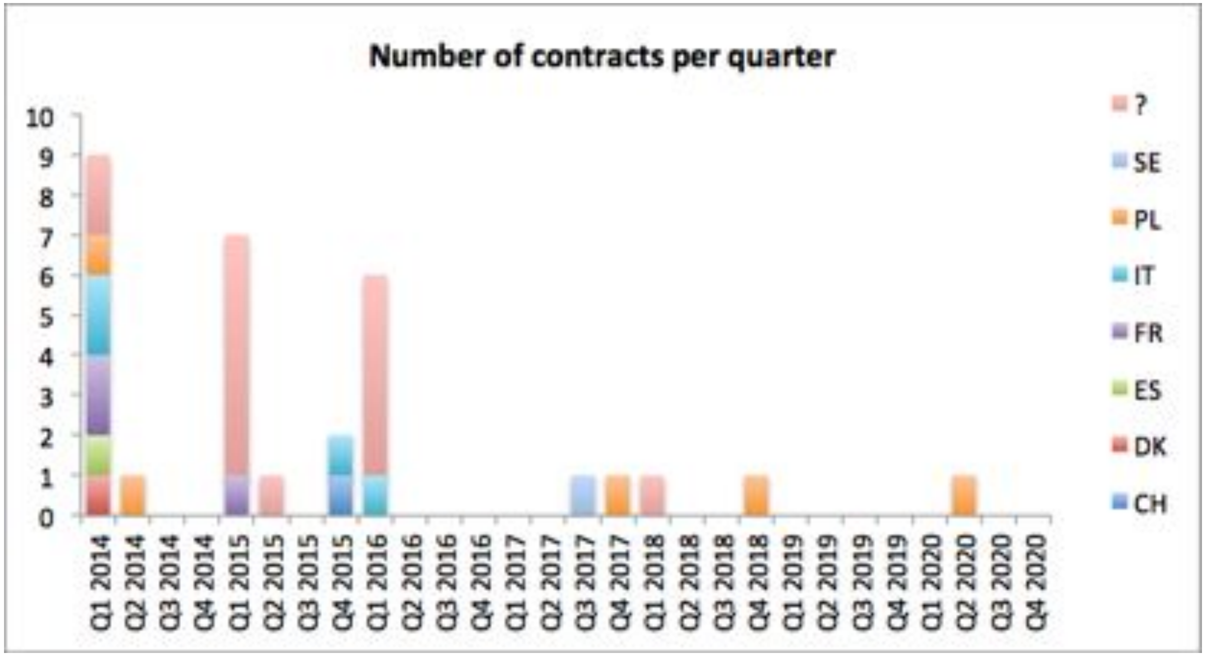
Activity	Country	Start date	Value
11.3.2 Proton Source and LEBT	IT	2014-01-07	3 897 412
11.3.3 RFQ	FR	2014-01-07	7 838 071
11.3.4 MEBT	ES	2014-01-07	1 541 521
11.3.5 DTL	IT	2014-01-07	16 178 720
11.4 Spoke Cavitites and Cryomodules	FR	2015-01-07	15 119 256
11.5 Elliptical Cavities and Cryomodules	FR	2014-02-03	99 978 029
11.6 HEBT and Conventional Magnet Systems	DK	2014-01-07	18 367 193
11.8.4.5 High power amplifiers Spoke	IT	2015-12-01	14 032 400
11.8.5 High Power Voltage Converters	CH	2015-12-01	42 750 000
11.8.8 RF installation phase 1	IT	2016-01-04	3 355 680
11.8.9 RF installation phase 2	PL	2018-12-17	3 606 720
11.10.4 Uppsala test stand	SE	2017-07-06	725 000
11.11.5 Cryogenic Distribution	PL	2014-06-12	12 543 200
11.99.3 Installation Non-conventional utilities	PL	2014-03-19	3 764 384
11.99.6 Installation phase 1	PL	2017-11-07	887 120
11.99.7 Installation phase 2	PL	2020-06-02	538 254
Sum			245 122 960

Summary of activities (work packages or work units) where at least one specific partner has been identified and discussions with this partner has started

Activity	Country	Start date	Value
11.7 Beam Diagnostics	?	2014-01-07	19 474 646
11.8.2 Low Level RF Control and control system	?	2016-01-07	13 789 257
11.8.3 Master Oscillator phase distribution	?	2016-03-23	81 000
11.8.4.2 High power amplifiers RFQ	?	2015-01-07	554 000
11.8.4.3 High power amplifiers MEBT	?	2016-03-01	210 000
11.8.4.4 High power amplifiers DTL	?	2015-01-07	2 674 000
11.8.4.6 High power amplifiers Medium Beta	?	2016-01-26	11 430 000
11.8.4.7 High power amplifiers High Beta	?	2018-01-03	26 630 000
11.8.6 RF Distribution	?	2016-01-07	21 462 800
11.10.2 Lund Test Stand 1 (LU)	?	2015-01-07	1 592 000
11.10.3 Lund Test Stand 2	?	2015-01-07	6 604 400
11.11.2 Accelerator Cryoplant	?	2015-02-04	34 789 200
11.11.3 Instruments and test stand cryoplant	?	2015-06-30	7 259 196
11.12 Vacuum	?	2015-01-07	8 175 160
11.99.8 Accelerator survey and alignment	?	2014-03-21	175 920
Sum			154 901 579

Summary of activities where no specific partner has been identified or, in the case of beam instrumentation, where the WP is being re-organized such that start dates and values cannot be assigned at the moment

Håkan Danared, IK manager ACCSYS



Many activities start Q1 2014, reflecting the importance of reaching agreements soon

- Planned in-kind contributions cover 48% of accelerator budget.
- Many items still open.
- Design phase is largely over – now hardware contributions are needed.
- To reach >50% in-kind to accelerator, substantial commercial items must be obtained as in-kind.
- Nevertheless, in-kind to construction is far from ”only procurement”.
- In-kind is also an opportunity to local industry (study showed 80% of procurement budget spent within 100 km of large research facilities).