Neutron Sources

Accelerator Physcs for Intense Ion Beams,

Bad Honnef, 18 Oct 2012

EUROPEAN SPALLATION SOURCE

Håkan Danared

Five Reasons for Using Neutrons

1. Thermal neutrons have a wavelength (2 Å) similar to interatomic distances, and an energy (20 meV) similar to elementary excitations in solids. One can thus obtain simultaneous information on the structure and dynamics of materials.

2. The neutron scattering cross section varies irregularly between elements and isotopes. In particular, it is high for hydrogen, which is almost invisible with X-rays. With neutrons, the large difference in scattering between ordinary hydrogen and deuterium can be used in polymer science and biological sciences to change the contrast in the scattering and to highlight selected groups of large molecules.

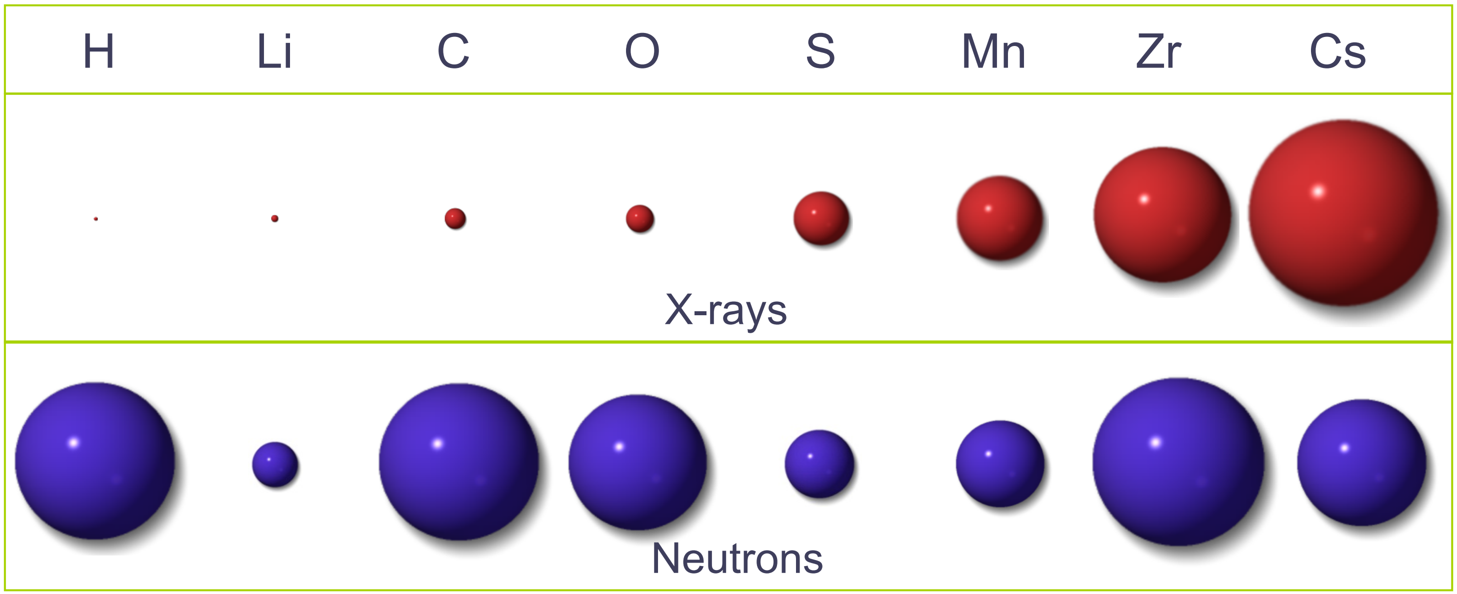
3. The interaction between neutrons and solids is rather weak, implying that neutrons in most cases probe the bulk of the sample, and not only its surface. In addition, quantitative comparisons between neutron scattering data and theoretical models are possible, since higher-order effects are small and can usually be corrected for or neglected.

4. Since neutrons penetrate matter easily, neutron scattering can be performed with samples stored in all sorts of sample environment: Cryostats, magnets, furnaces, pressure cells, etc. Furthermore, very bulky samples can be studied, up to 10 cm thickness, depending on its elemental composition.

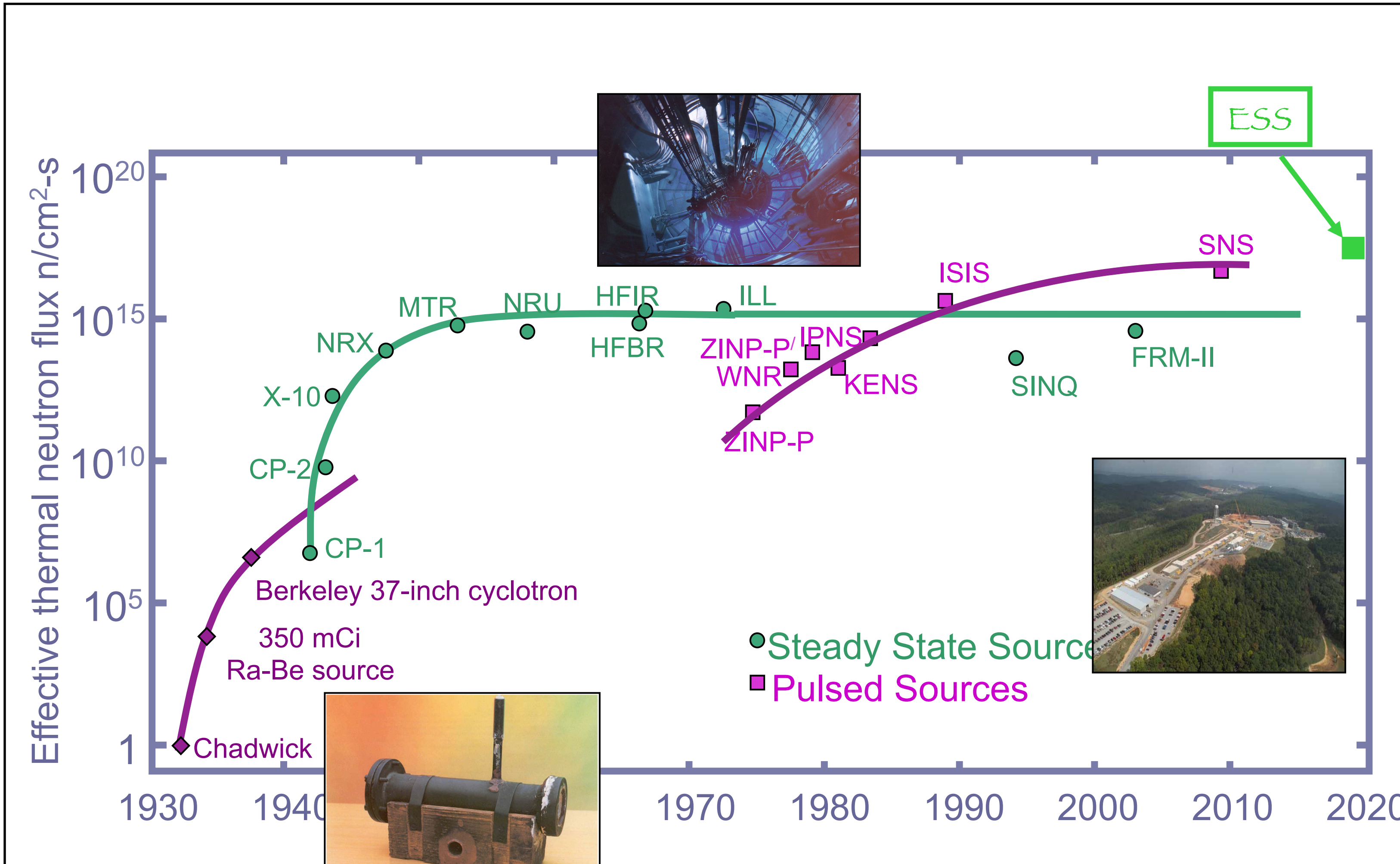
5. The neutron magnetic moment makes neutrons scatter from magnetic structures or magnetic field gradients. Unpolarized neutrons are used to learn about the periodicity and magnitude of the magnetic order, while scattering of spin-polarized neutrons can reveal the direction of the atomic magnetic moments.

From K. Lefmann

Neutron See the Nuclei...



Evolution of Neutron Sources

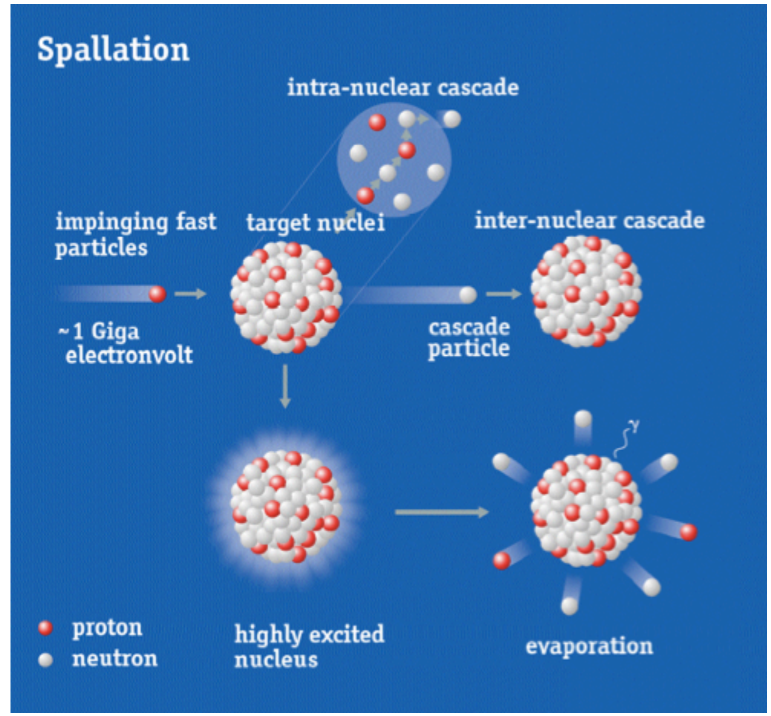


(... *Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

Spallation

In a spallation neutron source the neutrons are generated when GeV protons hit a heavy metal like Hg or W.

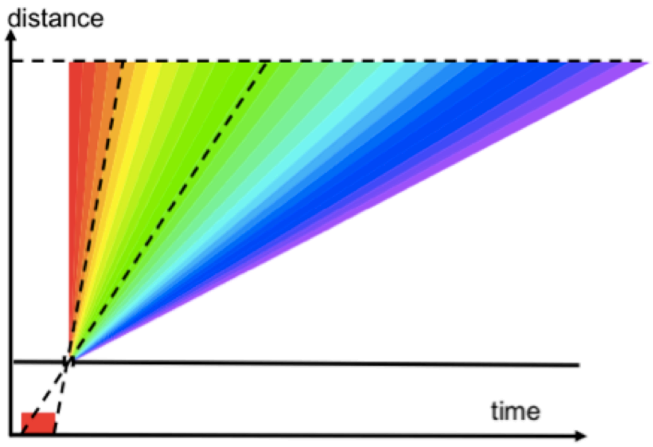
Through an “intra-nuclear cascade” secondary fast particles are produced, giving rise to an “inter-nuclear cascade”. A remaining highly excited nucleus relaxes through evaporation of lower-energy particles (< 20 MeV)



Time Structure

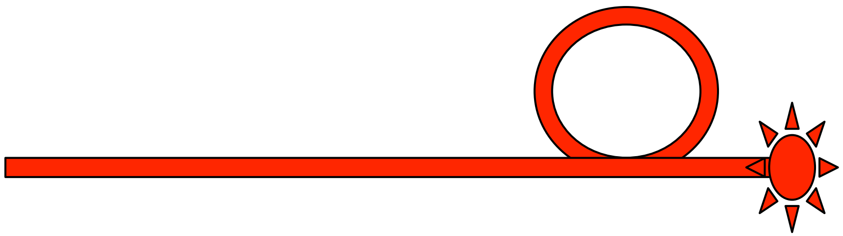
"Nearly all the neutrons generated in fission in a reactor are removed by using a monochromator, and measurements are then made continuously with a monochromatic beam. On a pulsed source the well-defined time origin of the neutron burst allows the dispersion of neutrons of different energies before the beam strikes the sample, and if the instrument is properly designed then these neutrons fill the whole measuring time frame with polychromatic (white) neutrons at peak intensity."

Willis and Carlile



There are short-pulse and long-pulse spallation sources.

In a short-pulse source, the beam pulse from a linac (~1 ms) is compressed in an accumulator ring and a much shorter (~1 μs) pulse is extracted from the ring. Short pulses are also obtained from synchrotrons.



A Note on Neutron Sources

The title of this presentation is “Neutron Sources”, and there are several types of accelerator-based neutron sources that don’t use the spallation process. Instead neutrons can be produced through

- ^{7}Li (p, n) ^{7}Be
- ^{9}Be (p, n) ^{9}B
- D (d, n) ^{3}He
- Bremsstrahlung (γ, n)
- ...

Applications can be

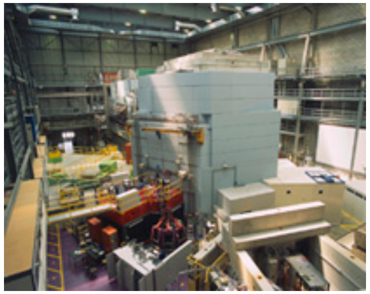
- Imaging
- Nuclear cross sections
- BNCT
- ...

These do not use the “intense ion beams” that are the topic of this school, and they will therefore not be discussed here.

Operating Spallation Neutron Sources

LANSCE, USA
1977–
Linac+ring
800 MeV
17 mA in linac
100 kW

ISIS, UK
1984–
RCS
800 MeV
200 mA extracted
160 kW



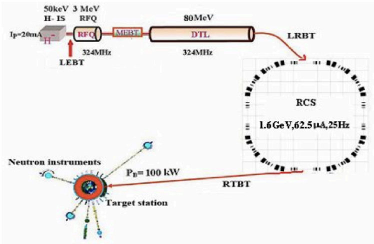
SINQ, Switzerland
1997–
Cyclotron
590 MeV
2.2 mA extracted
1.3 MW

SNS, USA
2006–
Linac+ring
1 GeV
26 mA in linac
1.4 MW

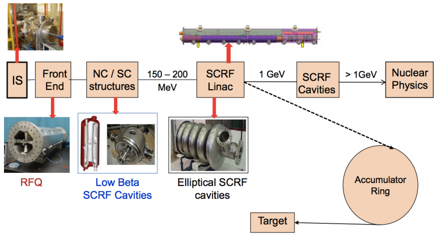
Figure 2 Overall image of J-PARC

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

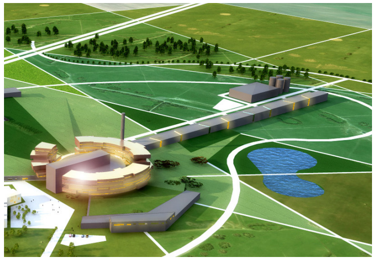
Planned Spallation Neutron Sources



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

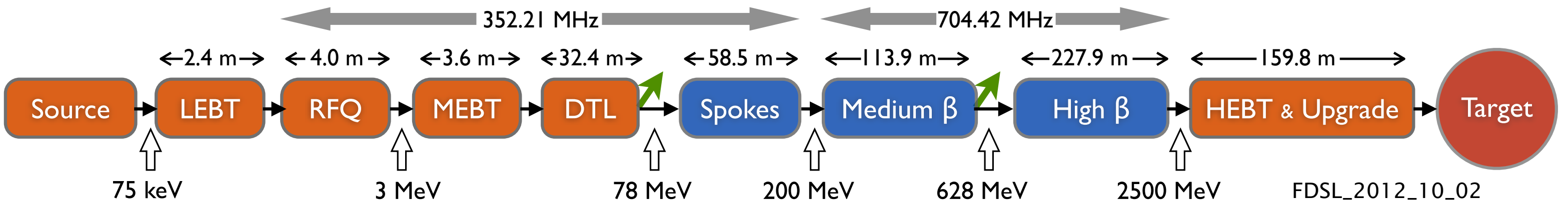


ISNS, India
Linac+ring
1 GeV
20–50 mA in linac
1 MW

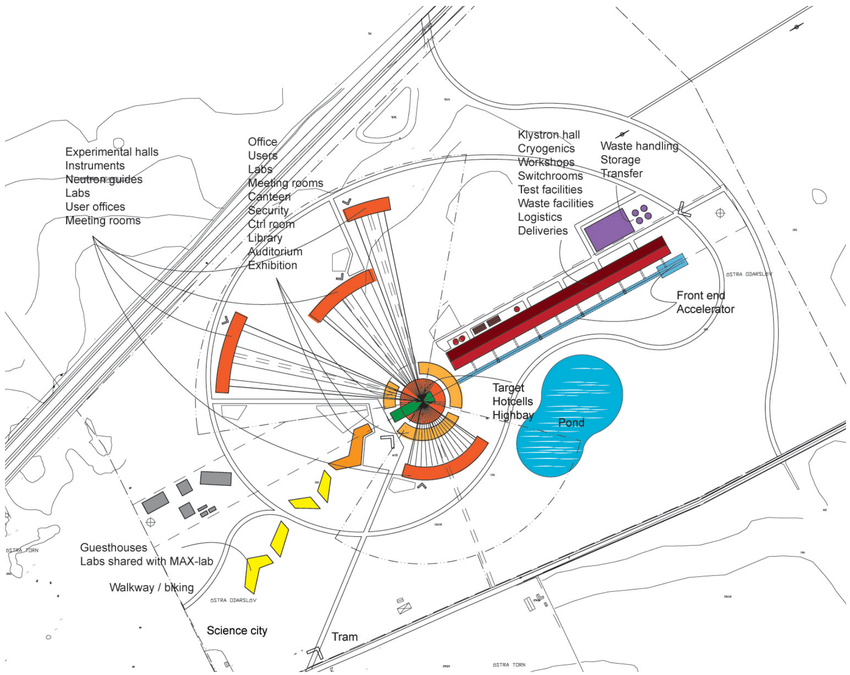


ESS, Sweden
2019–
Linac
2.5 GeV
50 mA
5 MW

ESS Linac Parameters



Particle species	p
Energy	2.5 GeV
Current	50 mA
Average power	5 MW
Peak power	125 MW
Pulse length	2.86 ms
Rep rate	14 Hz
Max cavity surface field	40 MV/m
Operating time	5200 h/year
Reliability (all facility)	95%



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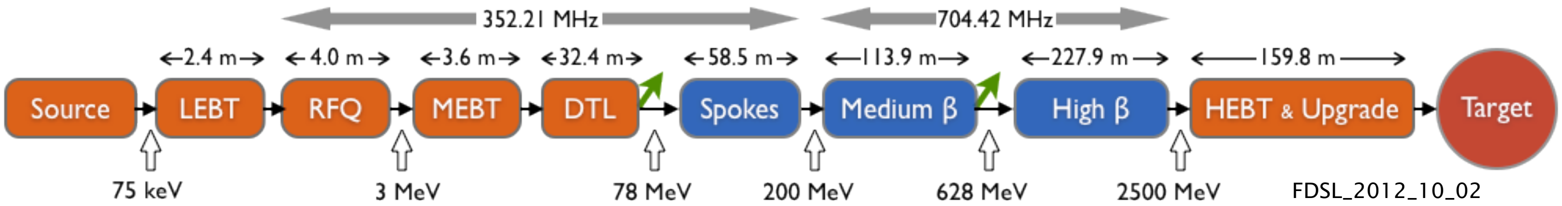
Linac Layout

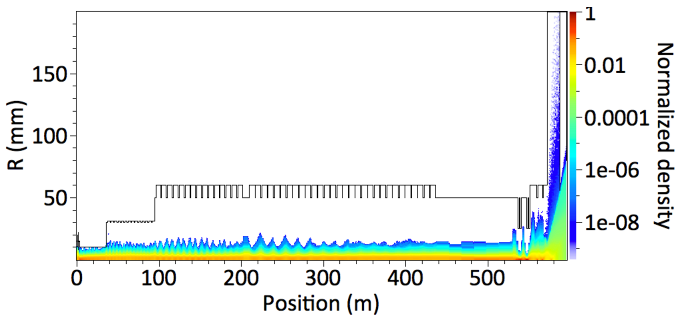


	Lab	E_{out} (MeV)	$Beta_{out}$	Length (m)	Temp (K)	Freq (MHz)
Proton source + LEBT	Catania	0.075	0.01	4.6	300	–
RFQ	Saclay	3	0.08	5.0	300	352.21
MEBT	Bilbao	3	0.08	3.5	300	352.21
DTL	Legnaro	79	0.39	32.5	300	352.21
Spoke cavities	Orsay	201	0.57	58.6	2	352.21
Medium-beta ellipticals	Saclay	623	0.80	113.9	2	704.42
High-beta ellipticals	Saclay	2500	0.96	227.9	2	704.42
HEBT	Aarhus	2500	0.96	159.2	300	–

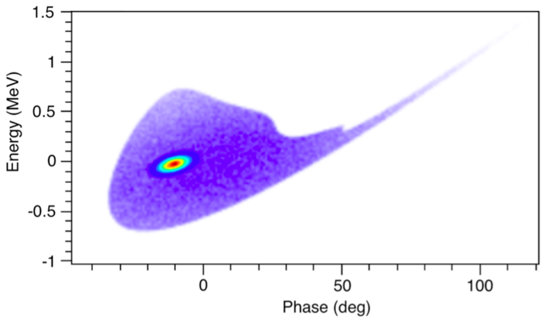
	Spoke resonators	Medium-beta ellipticals	High-beta ellipticals
Cells per cavity	3	5	5
Cavities per cryomodule	2	4	4
Number of cryomodules	14	15	30

Why these values?

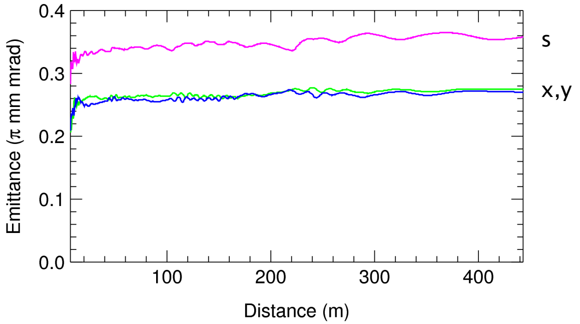
Beam Physics



Beam density from RFQ to target with aperture



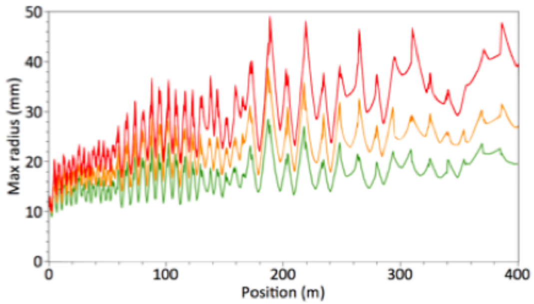
Longitudinal acceptance



Small emittance growths in all three planes

... although full beam size, including halo, is more important than RMS emittance

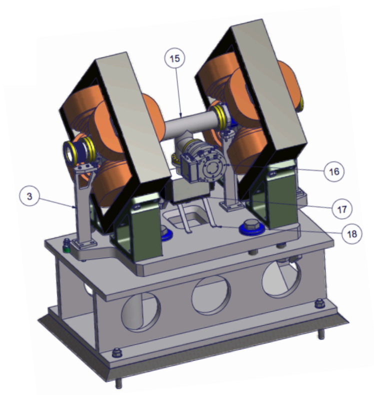
Maximum 1 W/m beam losses allowed



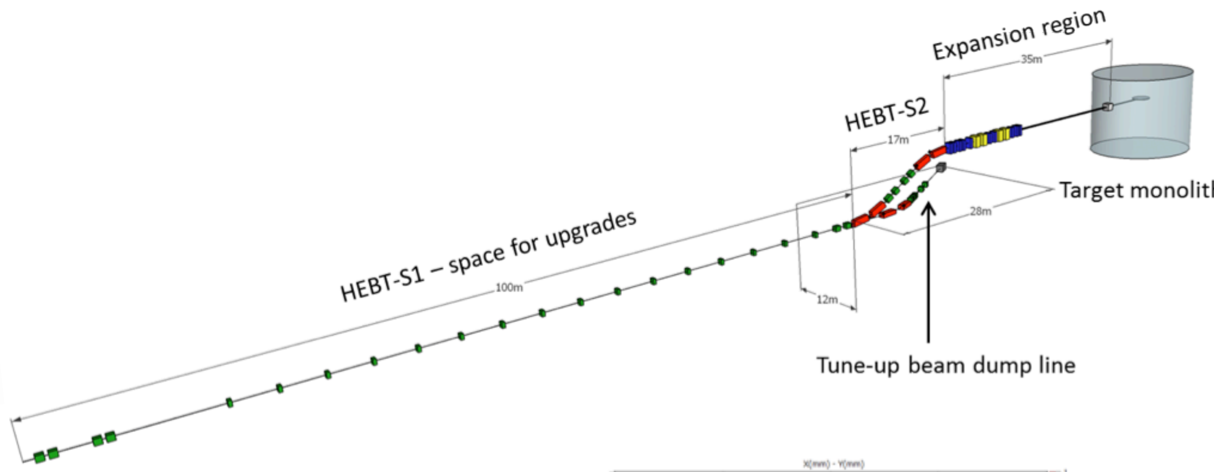
Effect of magnet misaligment, magnetic-field errors, RF jitter on beam radius. For three different magnitudes of errors

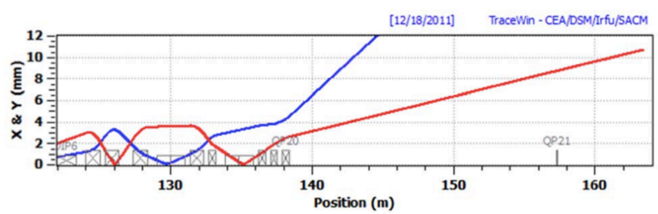
M. Eshraqi, R. Miyamoto, A. Ponton

High-Energy Beam Transport

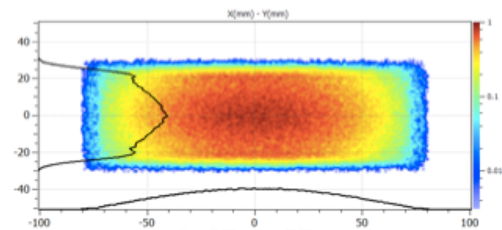


Quadrupole doublet
for linac and HEBT





Beam expansion on target with quadrupole
magnets plus two octupoles

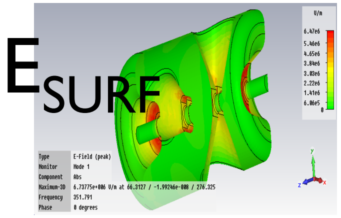


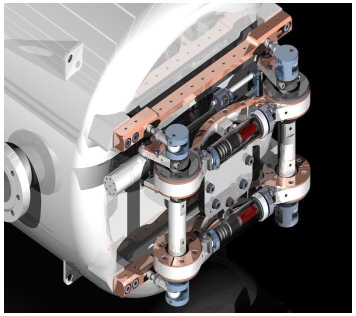
Example of beam profile on target (160 mm × 60 mm) with a peak current density of 49 μA/cm²

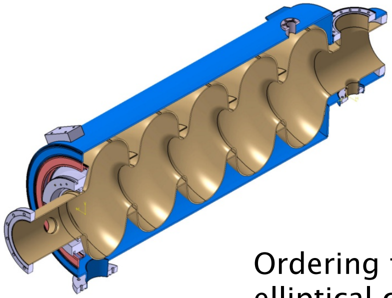
Fixed collimator outside proton-beam window with design depending on beam halo and acceptable peak current density

A.I.S. Holm, H.D. Thomsen, S.P. Møller

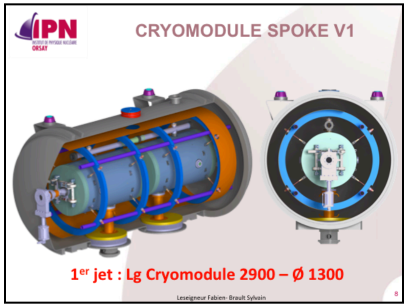
Cavities and Cryomodules

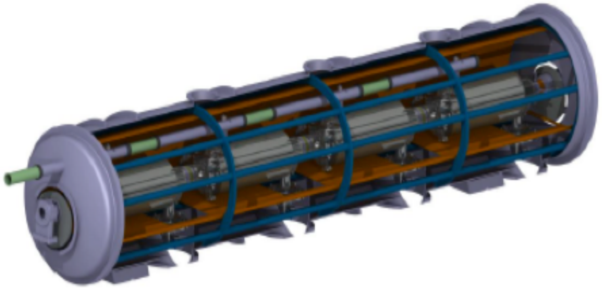






Ordering for high-beta elliptical cavitiy prototypes on-going at CEA, Saclay

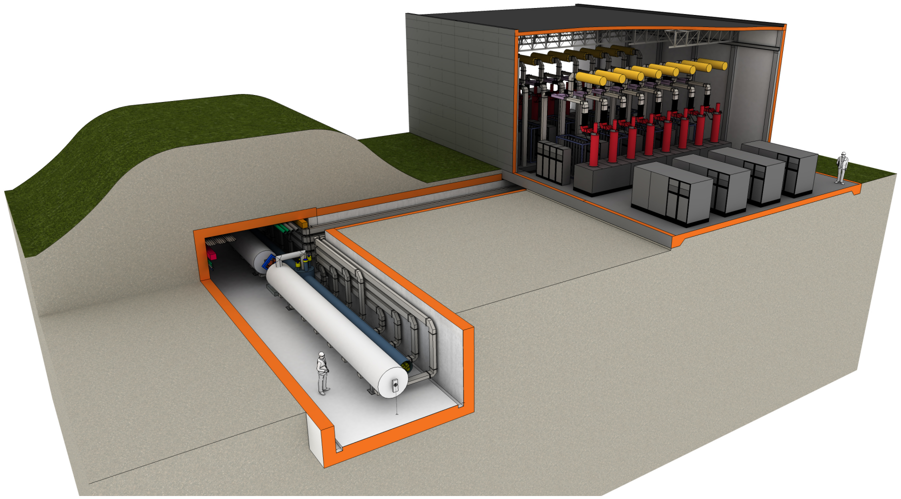




Spoke cavities and cryomodules:
Design is in progress at IPN, Orsay,

Elliptical modules: Design is in progress at CEA, Saclay and IPN, Orsay. In addition R&D is done in collaboration with CERN

RF Systems

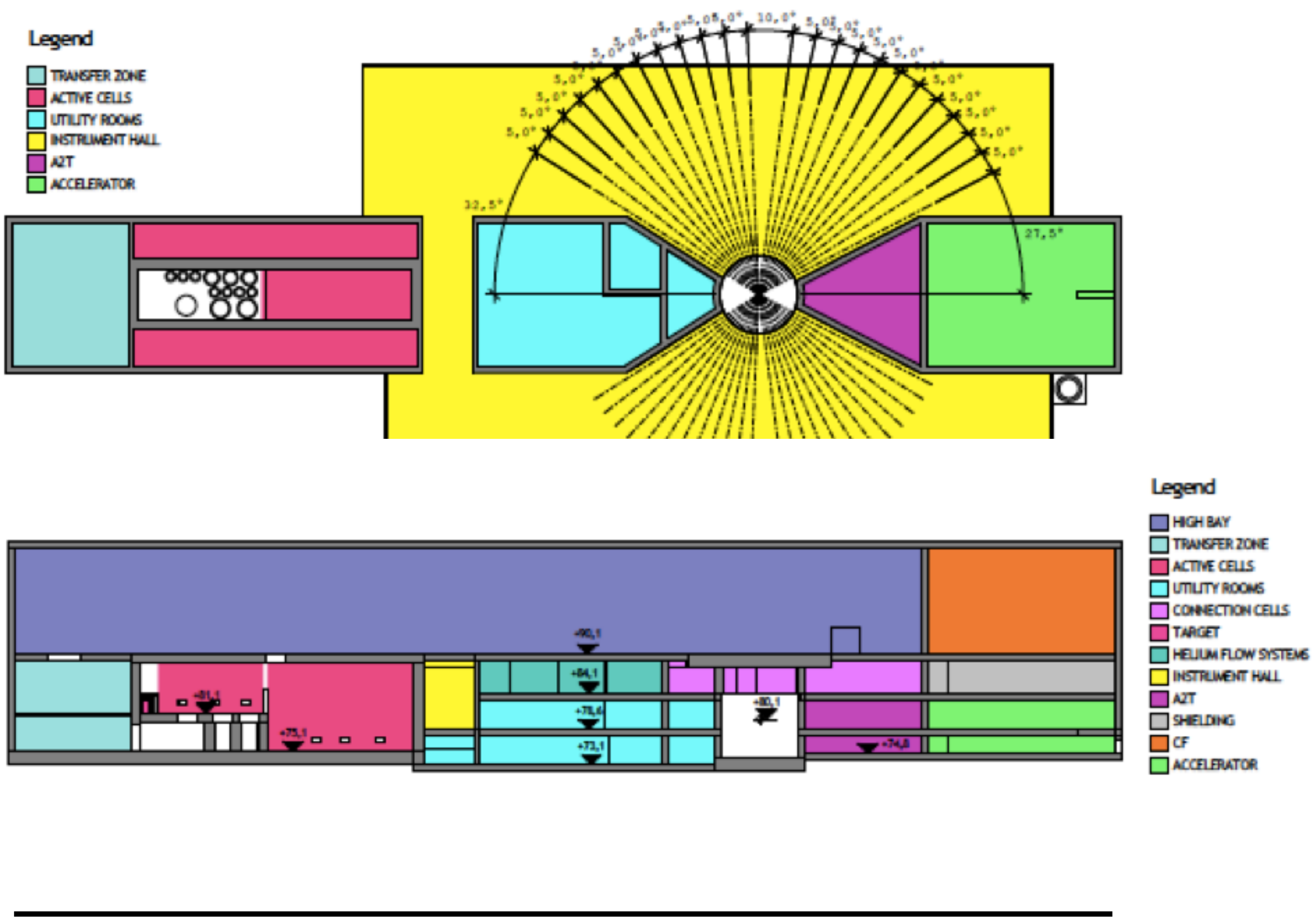


	Frequency (MHz)	No. of couplers	Max power (kW)
RFQ	352.21	1	900
DTL	352.21	4	2150
Spokes	352.21	28	280
Medium betas	704.42	60	560
High betas	704.42	129	850

Main features:

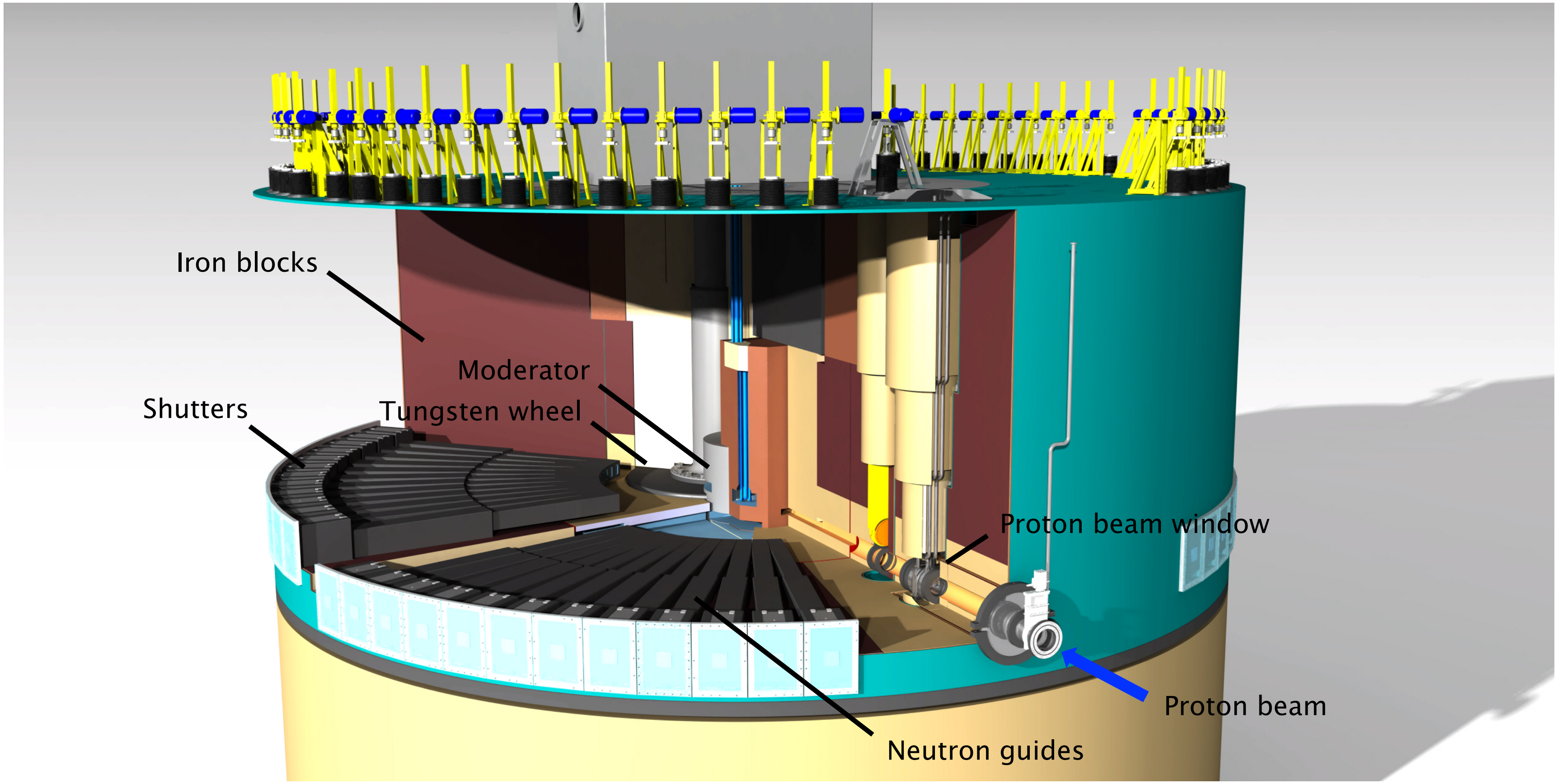
- One RF power source (klystron, IOT, ...) per resonator
- Two klystrons per modulator for ellipticals
- Pulsed-cathode klystrons for ellipticals, DTL and RFQ
- Gridded tubes (IOTs) for spokes
- Klystrons grouped across RF gallery
- Bundled waveguide layout

Target Building

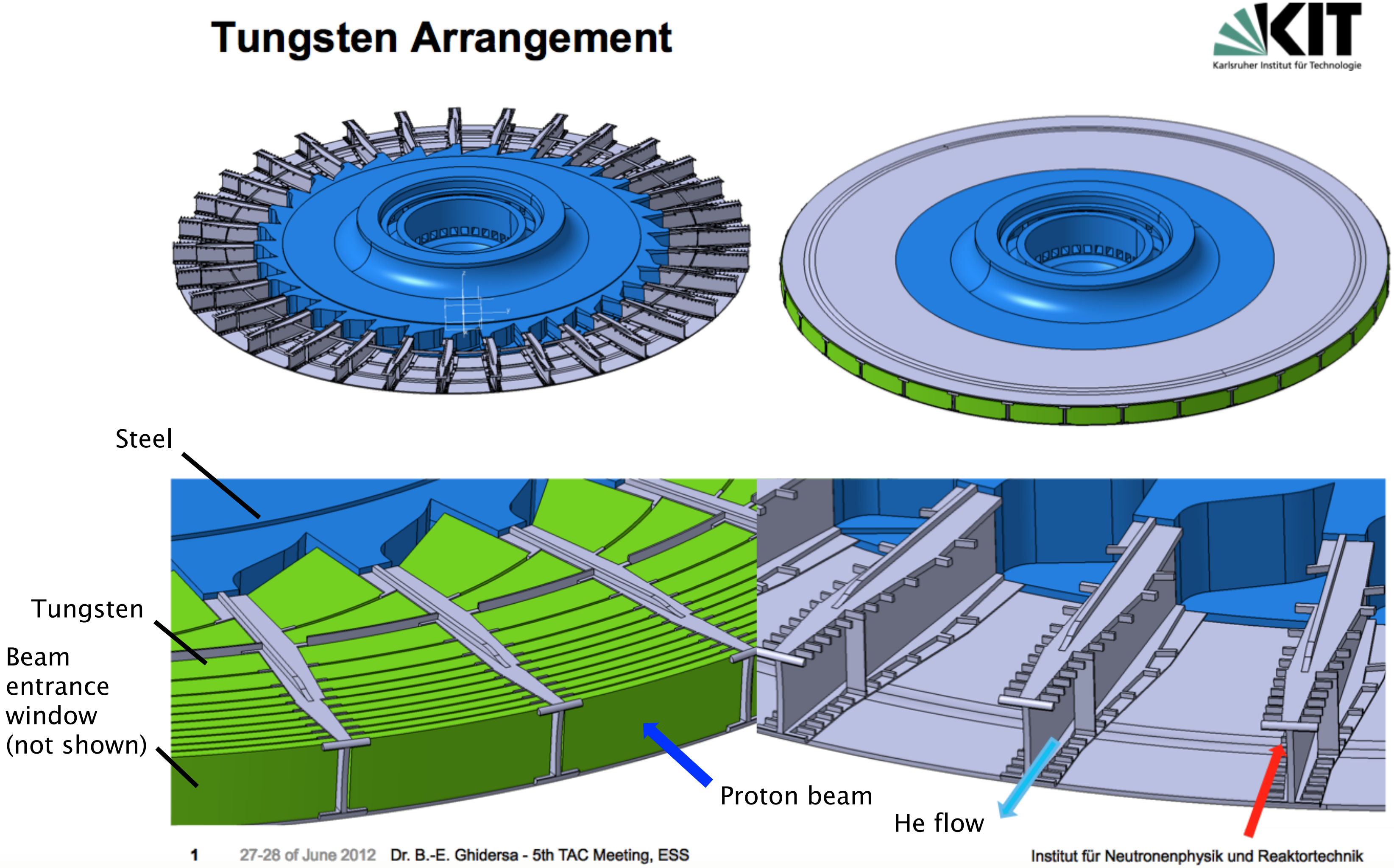


140 m

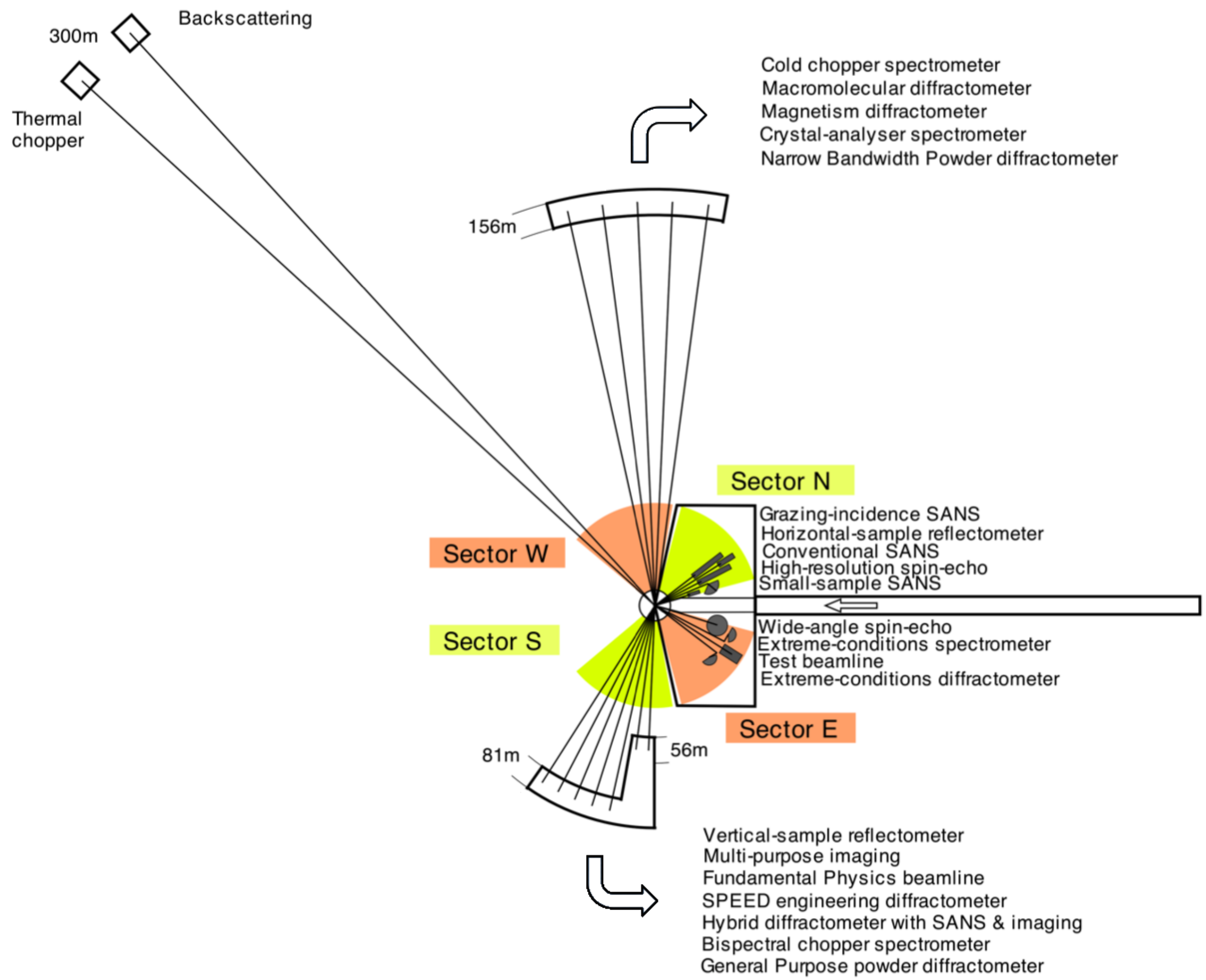
Target Monolith



Target Wheel Design



Neutron Instruments



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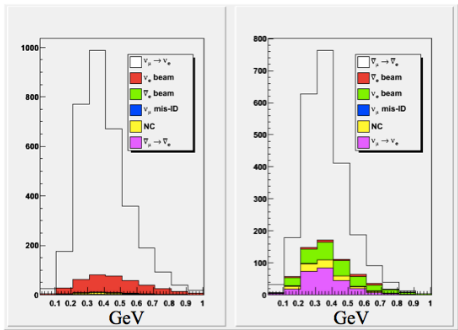
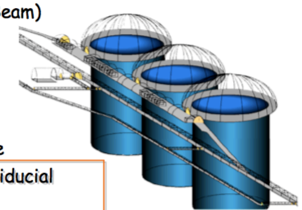
Fundamental Physics (from Tord Ekelöf)

ν_e and anti-ν_e energy spectra at 150 km from Lund around the first oscillation maximum



The MEMPHYS Project (within FP7 LAGUNA)

A "Hyperkamiokande" detector to study
- Neutrinos from accelerators (Super Beam)
- Supernovae (burst + "relics")
- Solar neutrinos
- Atmospheric neutrino
- Geoneutrinos
- Proton decay up to ~35 years life time



Water Cerenkov Detector with total fiducial mass: 440 kt:
- 3 Cylindrical modules 65x65 m
- Readout: 3x81k 12" PMTs, 30% geom. cover. (#PEs =40% cov. with 20" PMTs).

(arXiv: hep-ex/0607026)

Order of magnitude cost : 700 MEuro

Different base-line lengths from ESS Lund

Zinkgruvan mine 360 km
1200 m deep

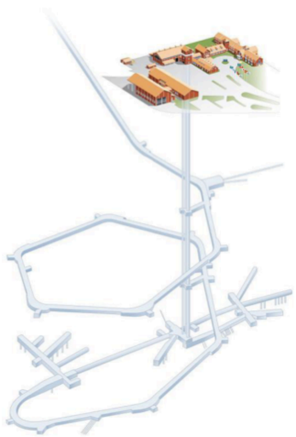
Oskarshamn nuclear waste depository 270 km
500 m deep

For 300 MeV $\nu_\mu \to \nu_e$
First minimum 140 km
Second maximum 430 km

Oskarshamn nuclear waste depository

Distance from ESS Lund 270 km

Depth 460 m
Access tunnel 3.6 km
Personnel hoist shaft diam. 4m
Two ventilation shafts diam. 1.5 m
The rock is investigated down to 1 000 m.



International collaboration

Sweden, Denmark and Norway cover 50% of construction cost

Remaining 50% from European partners

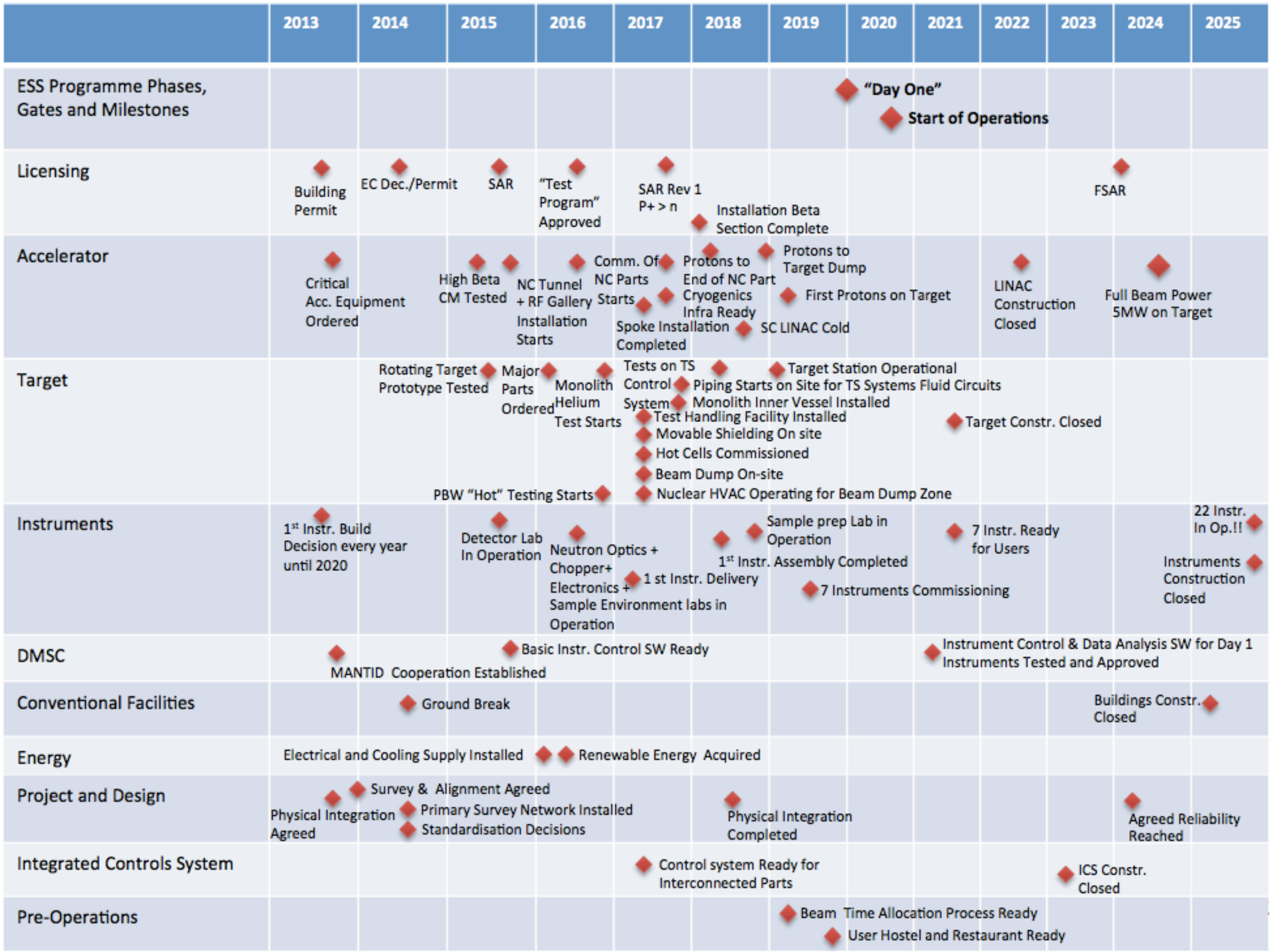
Letters of intent from 17 European states

Multilateral MoU for pre-construction signed in Paris 11 Feb 2012

ESS Milestones 2012

	Q1, 2012	Q2, 2012	Q3, 2012	Q4, 2012	2013
Executive Report	03-23		08-03	10-03, 12-03	
Programme Plan	03-19	06-11		10-01, 12-10	01-21
Technical design Report		06-25		10-01, 10-29, 12-10	
Project Specifications, Construction		06-11		10-29	01-21
Prel. Project Spec., Operations				10-01	01-01
Prel. Project Spec., De-comm.				10-01	01-01
Transition Plan to Operations			08-15	10-01	01-21
Budget and Cost Book		06-11		10-01, 12-08	01-21
Risk List Summary	01-23		07-02	10-01, 12-08	
ESS Framework Project (*QMP*)	03-31	06-30	09-30	12-31	01-21
ESS Board Meetings	02-08, 03-20	04-24, 06-04	08-14, 08-24	10-24, 11-16	01-18
STC meetings	01-11/12	05-10/11	09-13/14	12-17/18	
AFC meetings		04-12	07-02/03	10-22/23	
SAC meetings	03-21/22	06-07/08		11-07/08	
TAC meetings	02-15/17	06-27/28		11-14/15	

ESS Master Programme Plan



A Green Field Today...

Neutrons at ESS in 2019