Computational Challenges in ESS

EUROPEAN SPALLATION SOURCE

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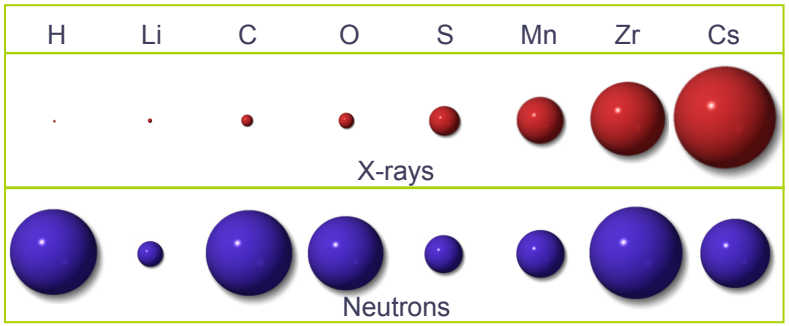
Collaborators at ESS
in Lund and at our
European partners

Why Neutrons?

- Thermal neutrons have a wavelength (2 Å) similar to inter-atomic 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.

- The neutron scattering cross section varies between elements and even between different isotopes of the same element in a way that is very different from the x-ray cross section. In particular, hydrogen which is almost invisible with x rays has a large neutron cross section, and deuterium is again different.



- The interaction between neutrons and solids is rather weak, suchthat neutrons in most cases probe the bulk of the sample, and not only its surface.

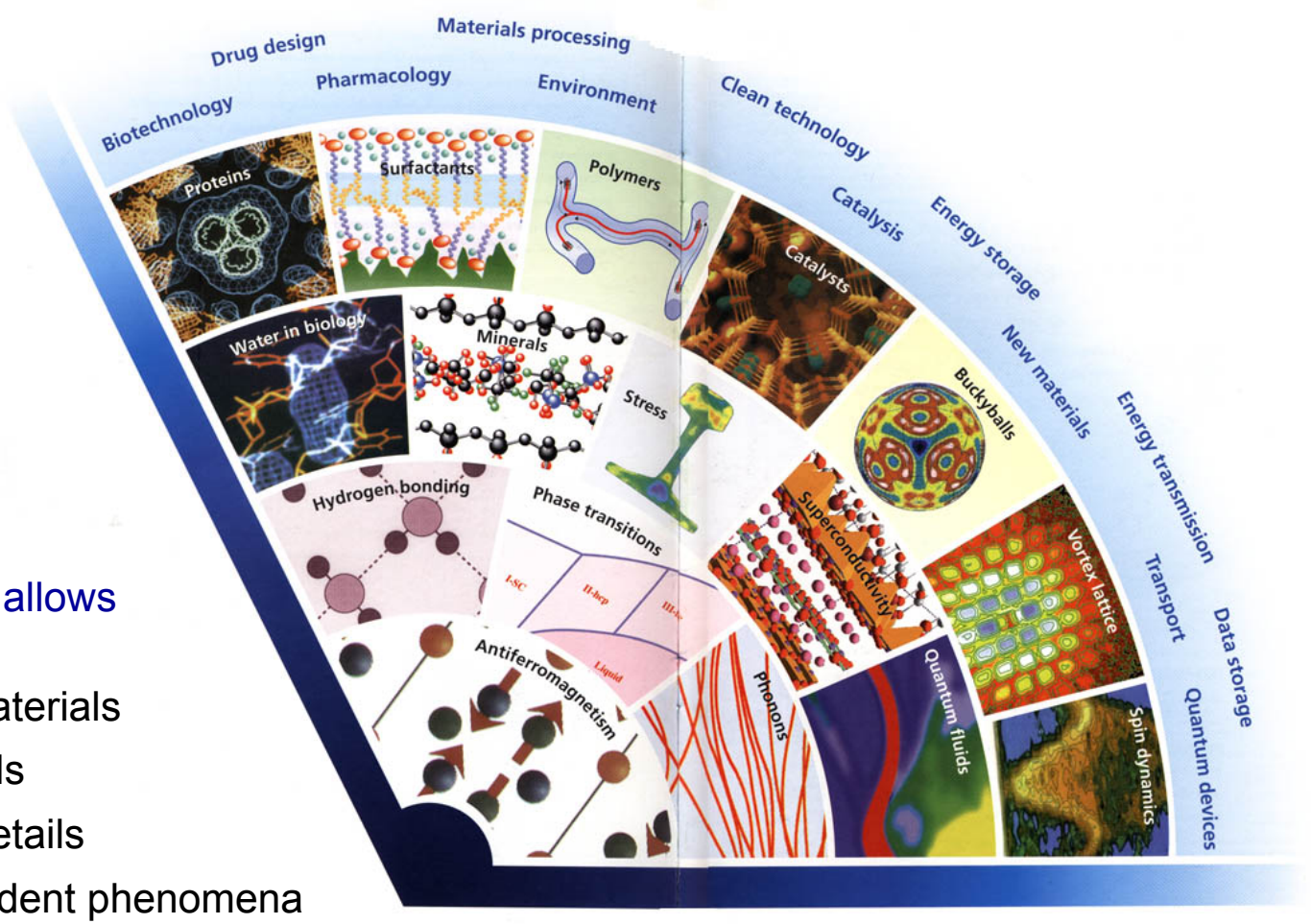
- Since neutrons penetrate matter easily, neutron scattering can be performed with samples stored in all sorts of sample environment: Cryostats, magnets, furnaces, pressure cells, etc. Furthermore, very bulky samples can be studied, up to 10 cm thickness, depending on its elemental composition.

- The neutron magnetic moment makes neutrons scatter from magnetic structures or magnetic field gradients.

From K. Lefmann

Neutron Science and Neutron Flux

Complexity/
Count-rate

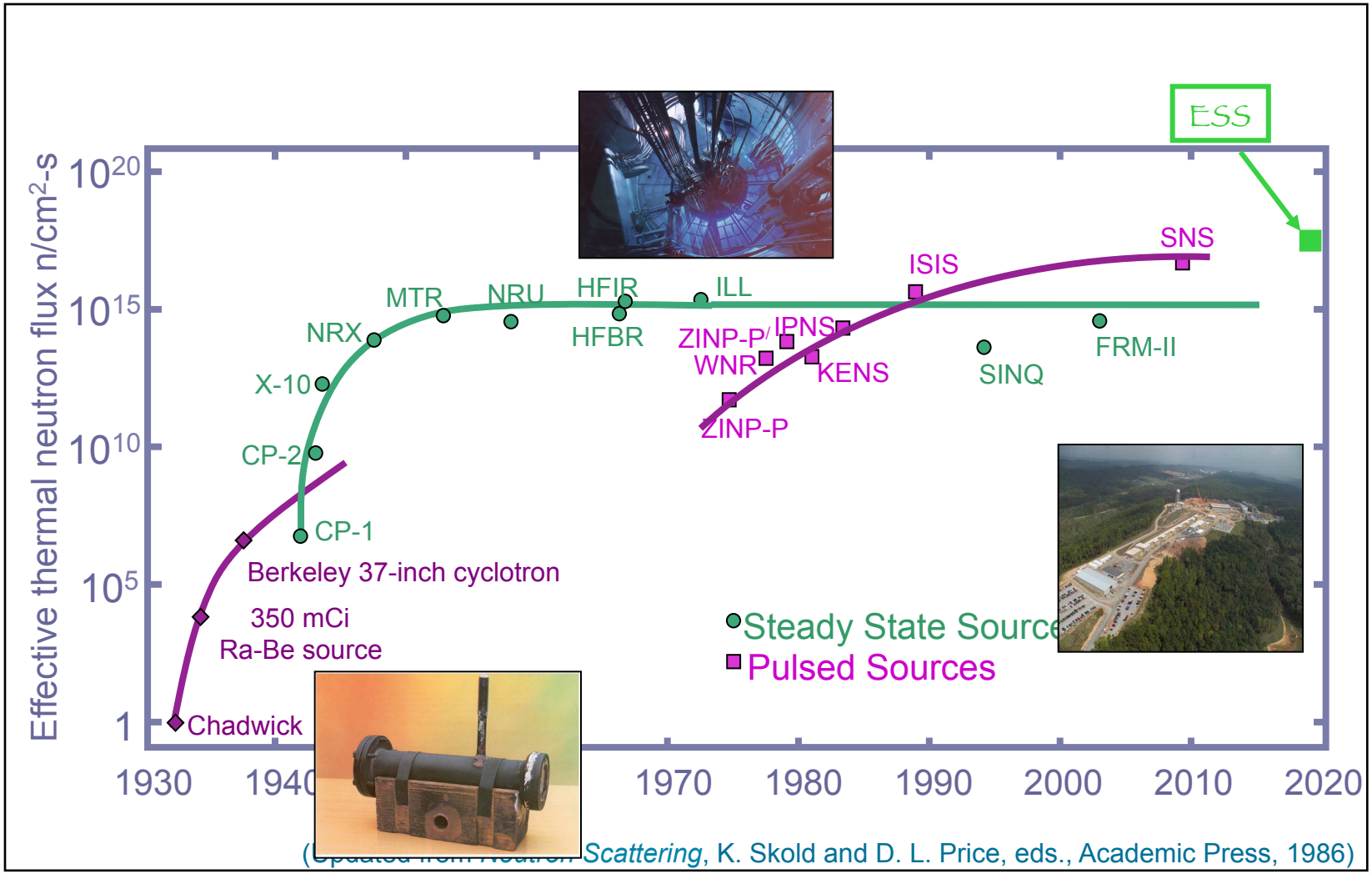


ESS intensity allows studies of

– Complex materials
– Weak signals
– Important details
– Time dependent phenomena

Details/Resolution

Evolution of Neutron Sources



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

International collaboration

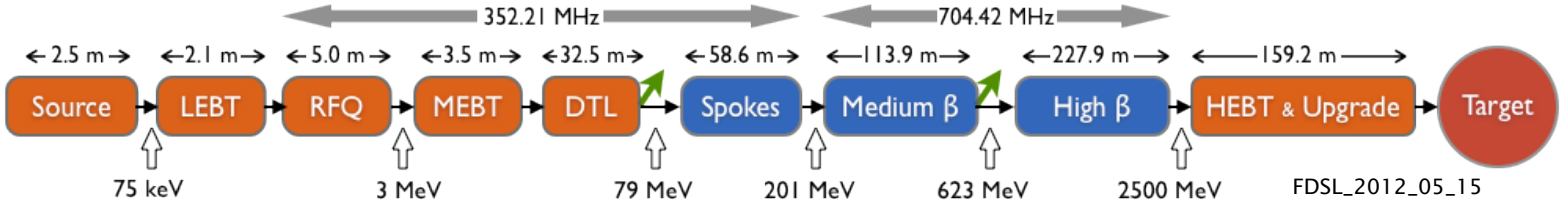
Sweden, Denmark and Norway cover 50% of construction cost

Remaining 50% from European partners

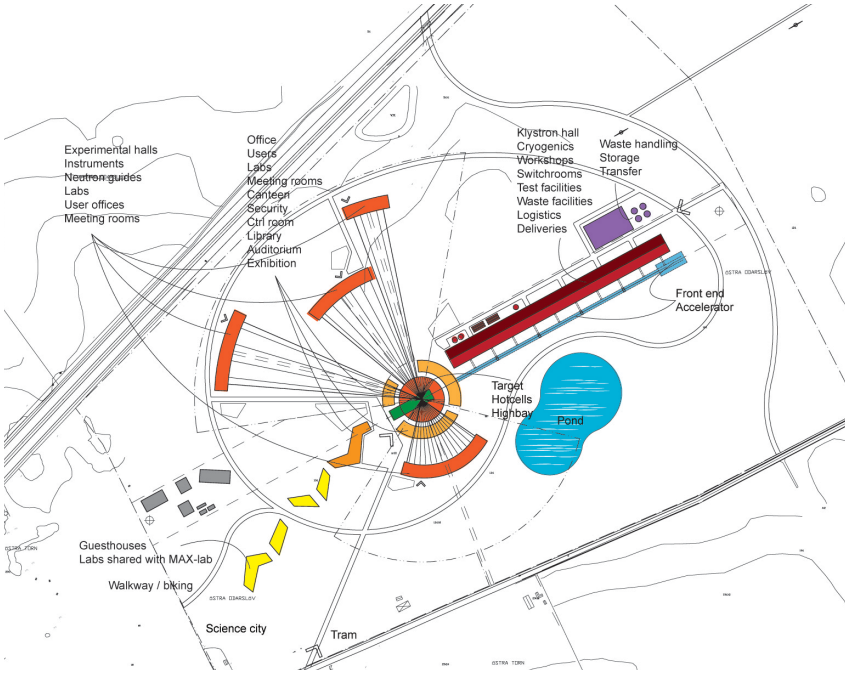
Letters of intent from 17 European states

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

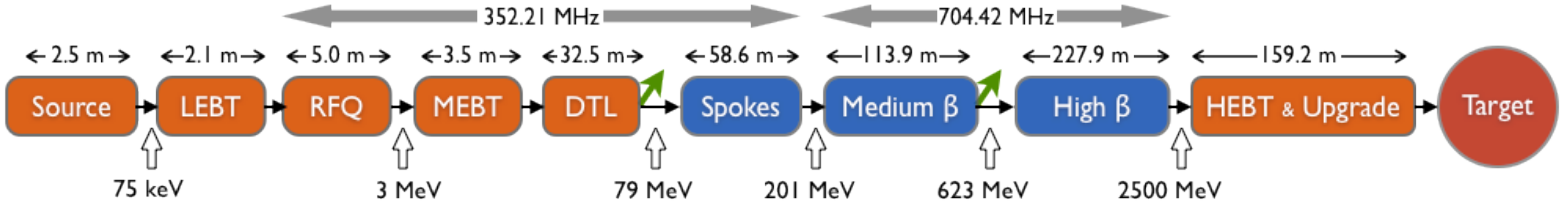
ESS Linac Parameters



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%



Linac Layout



	Lab	E_{out} (MeV)	$Beta_{out}$	Length (m)	Temp (K)	Freq (MHz)
Ion 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

Examples of Computational Tasks

Beam dynamics
- To verify losses less than 1 W/m
- Error studies to find mechanical and electromagnetic tolerances
- Survivability in fault scenarios
- Influence of cavity HOMs/SOMs on beam

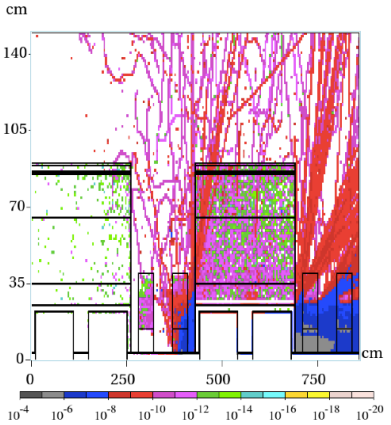
Beam instrumentation
- Beam-loss monitoring →

Collimation/activation/radio protection
- Is 1 W/m the right criterion?
- Can beam losses be reduced through collimation?
- Rad-hard magnets in HEBT?
- Need for remote handling in HEBT?

Cavity/coupler design
- HOMs/SOMs
- Multipacting, field emission
- Thermo-mechanical

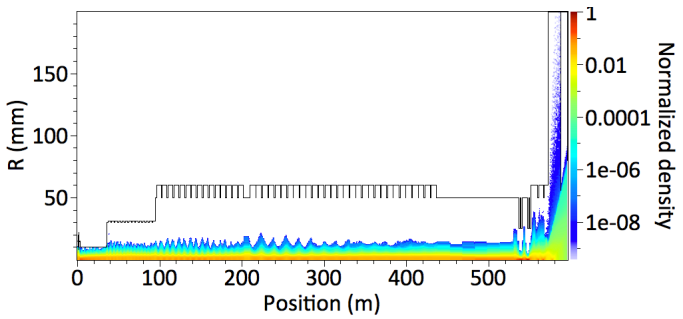
Target design
- Neutron yield
- Thermo-mechanical
- Window lifetime

Control system
- On-line model/XAL

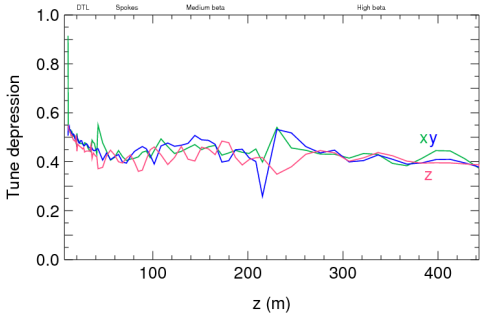


From L. Tchelidze

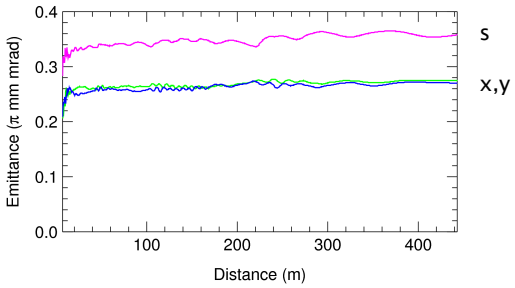
Beam Dynamics



Beam density from RFQ to target

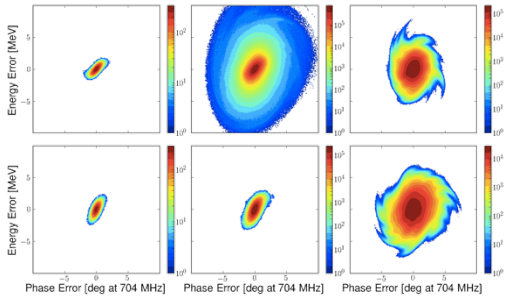


50 mA gives large tune depression k/k_0.



Small emittance growths in all three planes

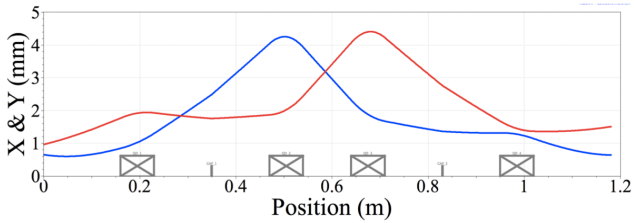
... although full beam size, including halo, is more important than RMS emittance



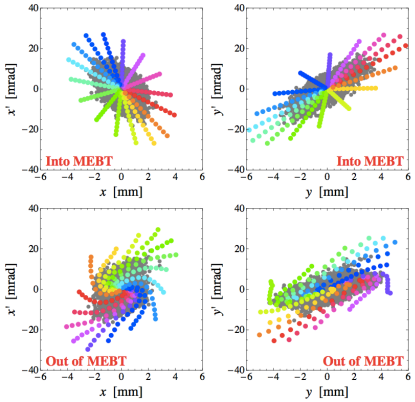
From R. Ainsworth

Long. phase space with SOMs in medium betas
Upper row "old" linac layout, lower current layout
Left: input distribution
Middle: with SOMs ($4\pi/5$ etc.)
Right: uniform RF errors

Beam Halo and Collimation

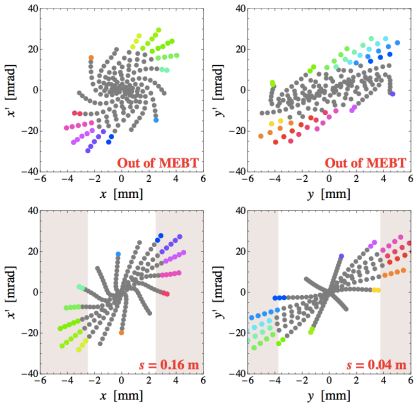


Simplified MEBT with four quadrupoles



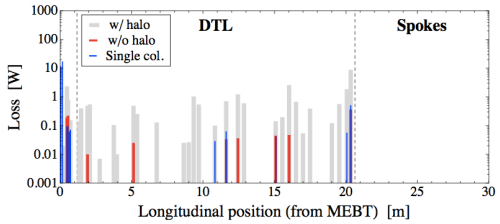
Beam core (grey) plus halo (colour) added ”by hand” (0.5σ, 1σ, ..., 6σ)

Into MEBT (top) and out of MEBT (bottom)



Particles outside of 5σ (colour) out of MEBT (top)

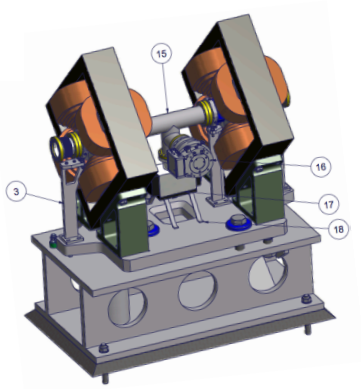
A position at the beginning of the MEBT can be found where these particles have large x or y and can be collimated (bottom)



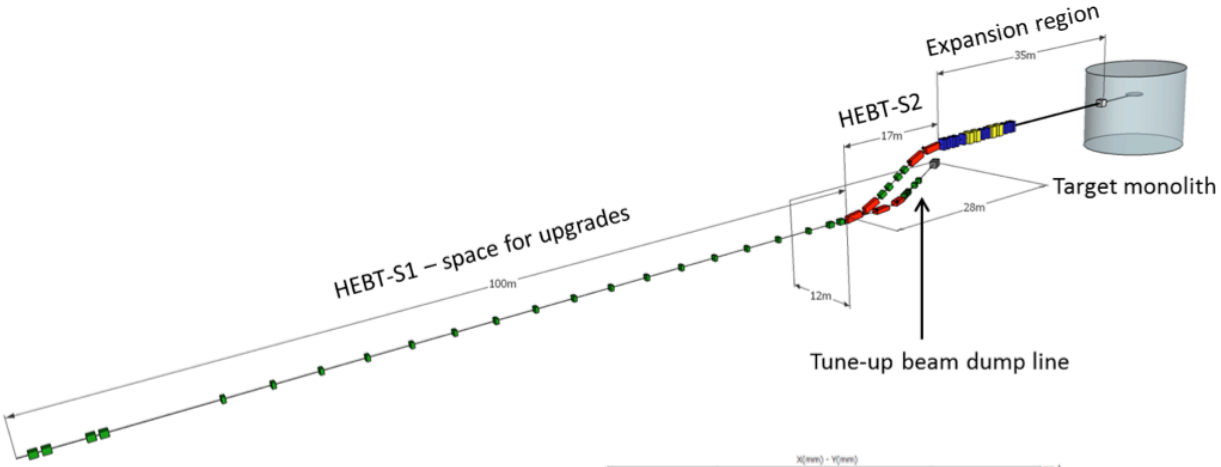
Beam losses in DTL and spokes with no halo (red), with halo (grey), with halo+coll (blue)

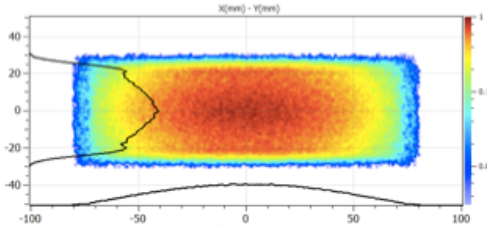
Work in progress...

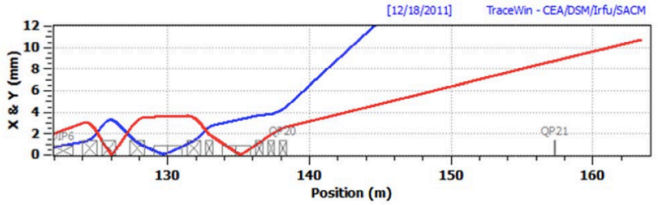
High-Energy Beam Transport



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/cm^2

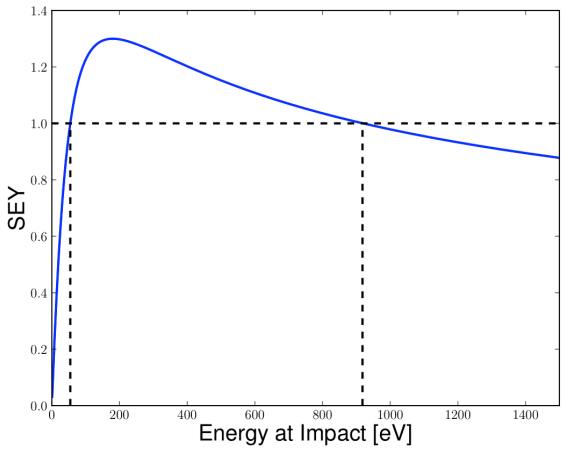
Fixed collimator outside proton-beam window with design depending on beam halo and acceptable peak current density

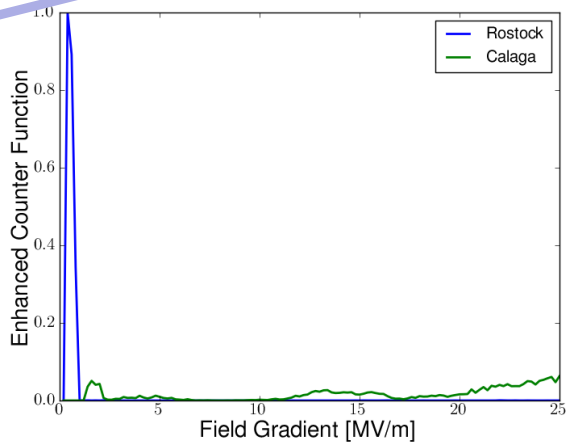
From A. Holm, H. Thomsen, S.P.Møller

Coupler Multipactor

A resonant cascade of electrons can occur within the complex geometry of a HOM coupler. This can be catastrophic to the operation of the cavity, and should be investigated. The highly non-linear properties of this phenomena demand significant computer resources.

Build cavity +coupler volume, and mesh → Find eigenmodes (using Omega3P) → Track electrons emitted from coupler surface (using Track3P) → Find resonant impacts & scale by SEY



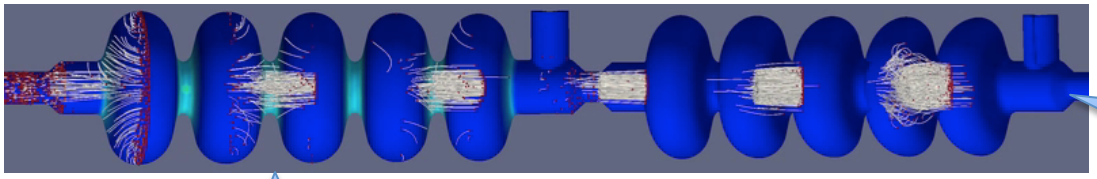


From S. Molloy

Propagation of Field-Emitted Electrons

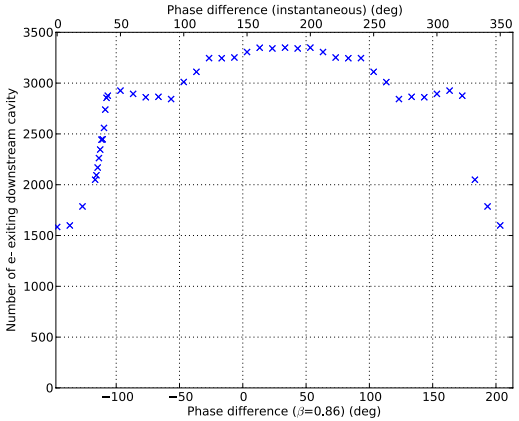
Electron loading of cavity end-groups may be a function of several cavities
- Observed in SNS

Studies require large volume and long time-scales
- Signficant computer resources



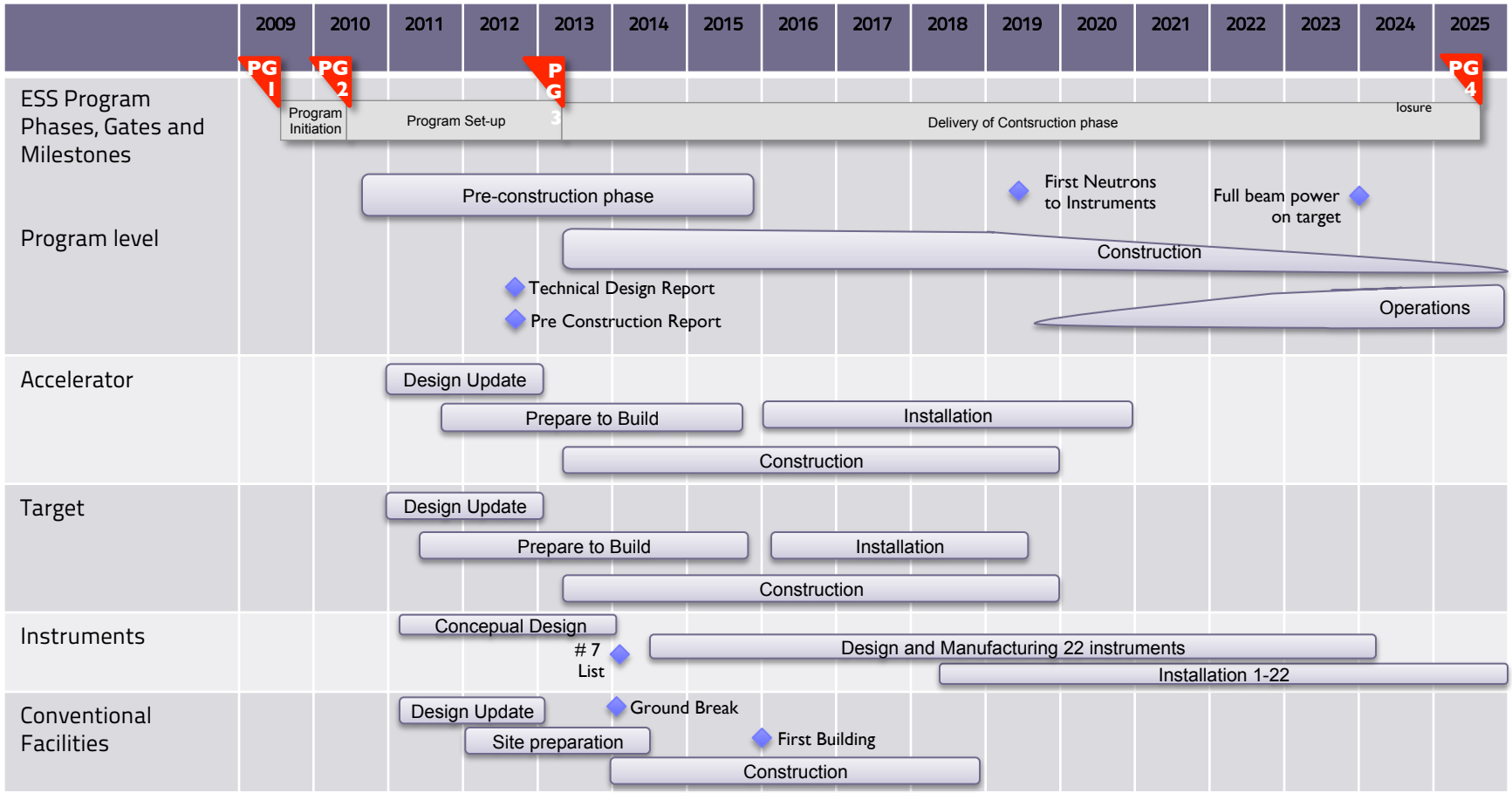
Monitor on this beam-pipe exit

Electrons released from all surfaces of this cavity



From S. Molloy

ESS Master Programme Schedule



A Green Field Today…

Neutrons in 2019!