7th High Power Targetry Workshop

The ESSνSB Target Station

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On behalf of the ESSνSB Collaboration

ESS NEUTRINO SUPER BEAM

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Outline

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- Overview of the ESSνSB (European Spallation Source Neutrino Super Beam) project
- The target station concept
- Overview of the target options
- The pebble-bed target
- Horn design
- Activation and environmental issues
- Summary

ESSνSB experiment

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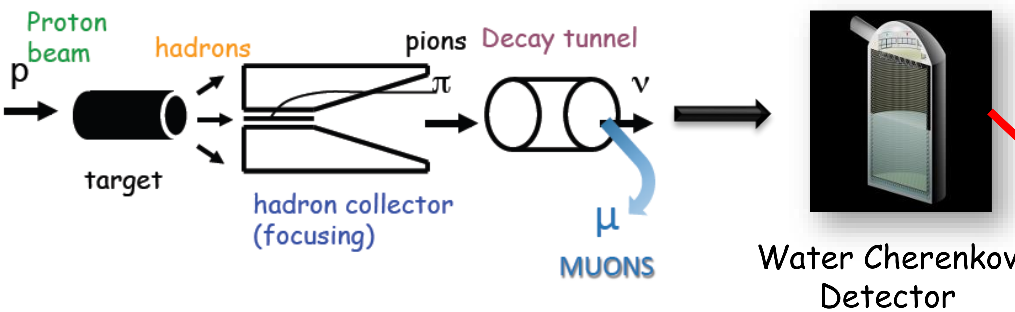
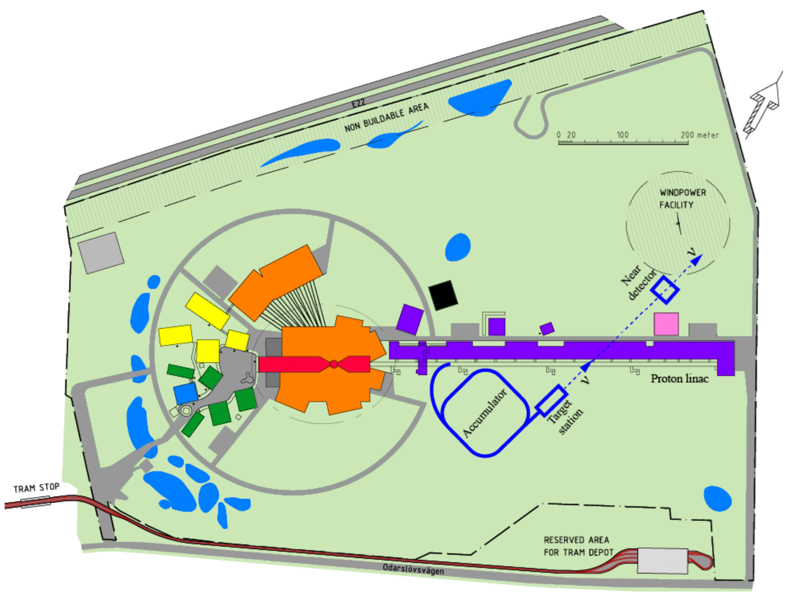


The far water Cherenkov detector will be placed at the second oscillation maximum, at the Garpenberg mine, 540 km from Lund

Given sufficient statistics, as obtainable with the ESS 5MW linac, the sensitivity to CP violation is 3 times higher at the second oscillation maximum, as compared to the first

ESSνSB experiment

How to add a neutrino facility to ESS?



« This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 777419 »

- Increase the ESS linac average power from 5 MW to 10 MW by increasing the linac pulse rate from 14 Hz to 28 Hz, implying that the linac duty cycle increases from 4% to 8%
- Inject into an accumulator ring (circumference ca 400 m) to compress the 3 ms proton pulse length to 1.5 μs, which is required by the operation of the neutrino horn (fed with 350 kA current pulses). The injection in the ring requires H^- pulses to be accelerated in the linac
- Add a neutrino target station (studied in EUROν)
- Build near and far neutrino detectors (studied in LAGUNA)

ESSνSB Horizon 2020 Design Study

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Duration: 1 January 2018 – 31 December 2021

Main aim:

The primary aim of the ESSνSB initiative is to measure the parameters of the neutrino oscillations, in particular the leptonic CP-violating phase angle δ_{CP}. This requires the production of a very intense neutrino beam, possible with the ESS proton linac.

Organization:

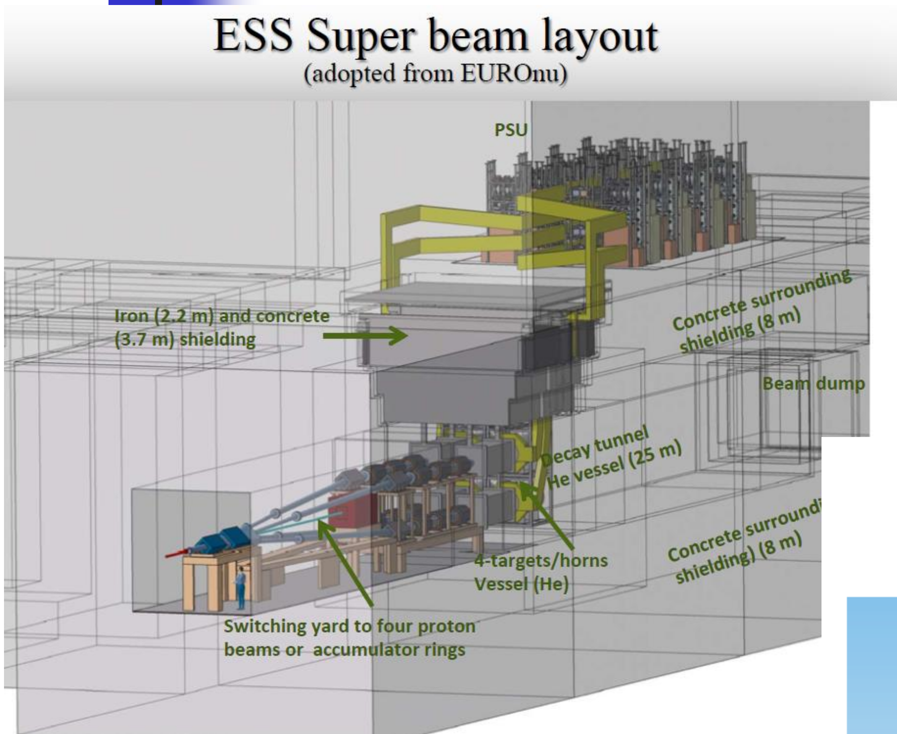
15 participating institutes, with CNRS (France) acting as coordinating institute.
Several collaborating institutes from outside the EU.

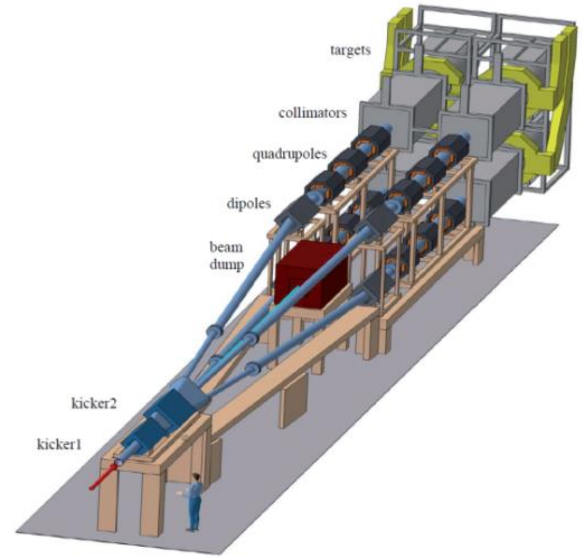
Web page: http://essnusb.eu/site/

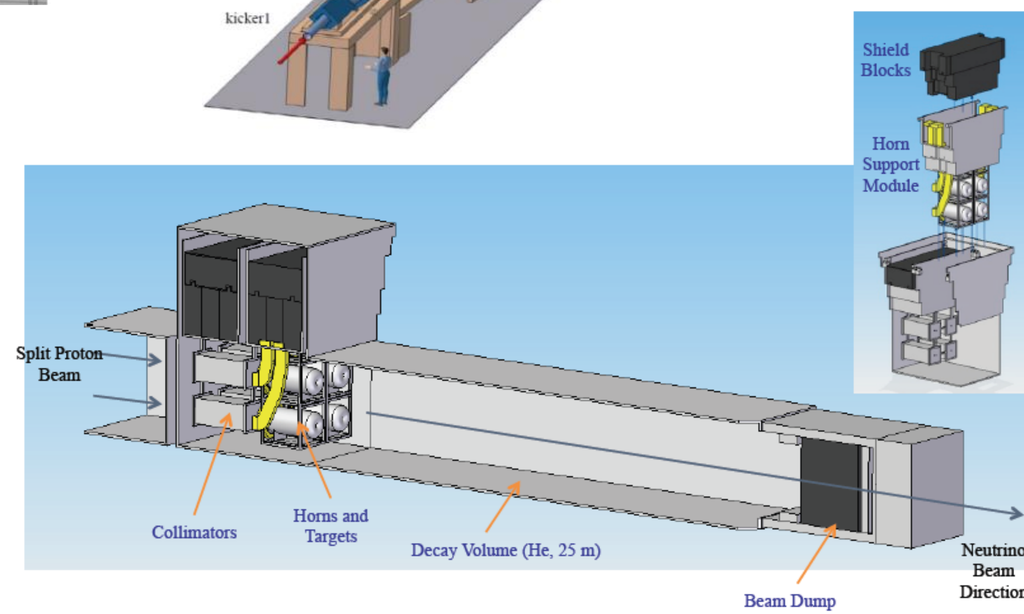
Some beam parameters

Parameter	SPL (EUROν)	ESS (ESSνSB)
Power (MW)	4	5
E_{p+} (GeV)	4.5	2, 2.5
Baseline (km)	130	365, 540
Target	Packed-bed	Packed-bed
Target length (cm)	78	53-78
Target radii (cm)	1.5	1.5
Horn	Forward closed	Forward closed
Horn current (kA)	350 @ 12.5 Hz	350 @ 3.5 Hz
# of horns/targets	4	4
Tunnel length (m)	25	15-25
Tunnel radii (m)	2	2
Exposure (years)	2 ν + 8 anti-ν	2 ν + 8 anti-ν

Target station concept







Different target options

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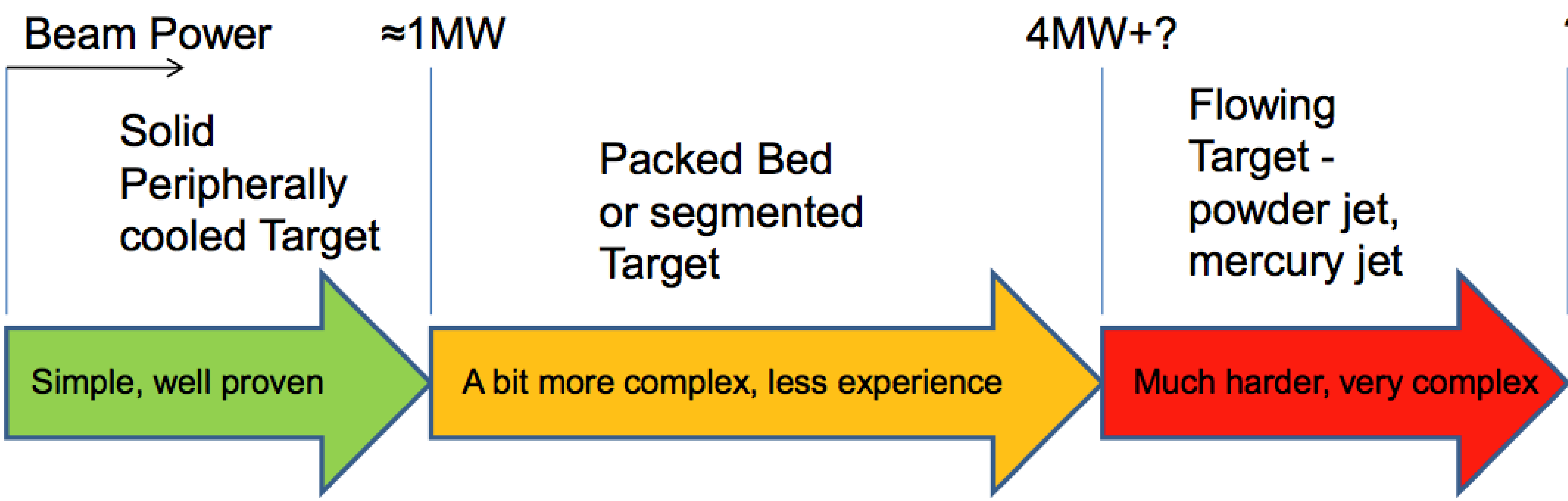

Limiting factors		
Heat Transfer Area Thermal and Inertial Stress Off axis beam	Helium Pressure Radiation damage Window components	Reliability Complexity Development Time

Liquid mercury target: serious environ-mental issues

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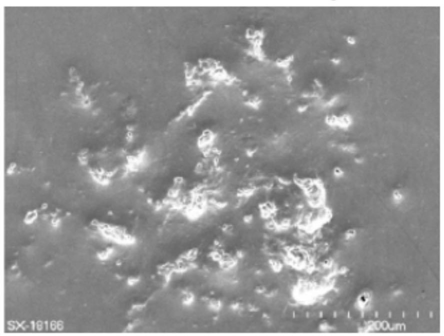
Liquid Target?

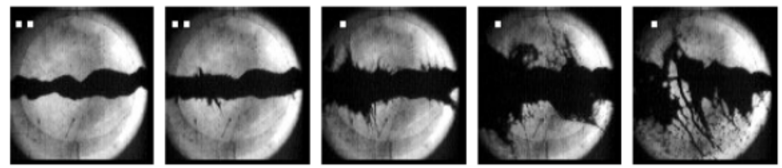
Studies made on Hg targets

Contained mercury



Cavitation damage in wall of Hg target container after 100 pulses of 19 J/cc proton beam (WNR facility at LANL)

Free mercury jet



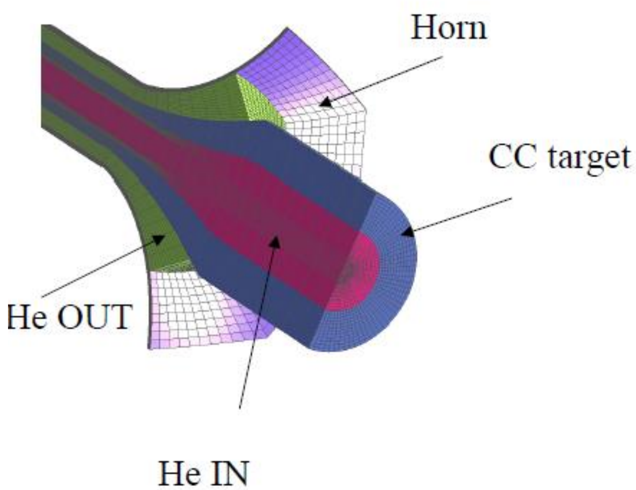
MERIT experiment: Beam-induced splashing of mercury jet (c.200 J/cc)

- Damping of splashes due to magnetic field observed as predicted
- More studies ongoing

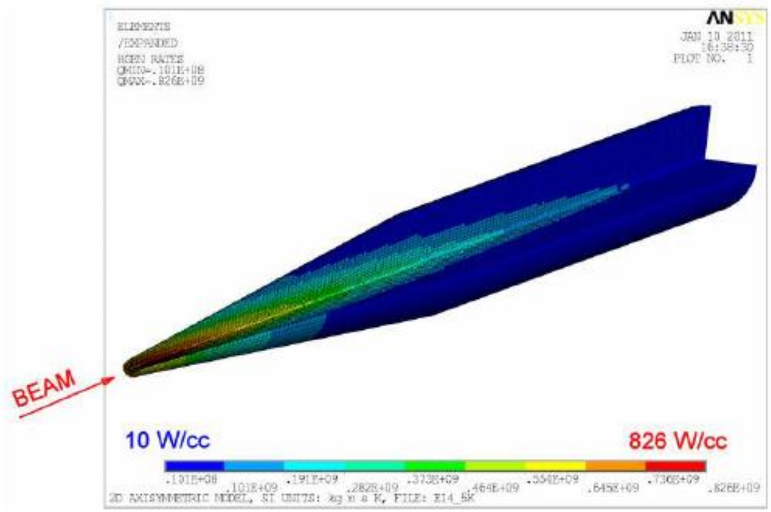
no problem with target cooling but…

- Magnetic horns are typically manufactured from aluminium alloy not compatible with Hg (severe and rapid erosion in addition to the shock wave problem)
- Is it possible to protect a horn with a material compatible with liquid Hg?
- B=0 inside horn, ie no magnetic damping of mercury jet as in MERIT experiment
- Combination of a mercury jet with a magnetic horn would appear to be extremely difficult.

Solid targets



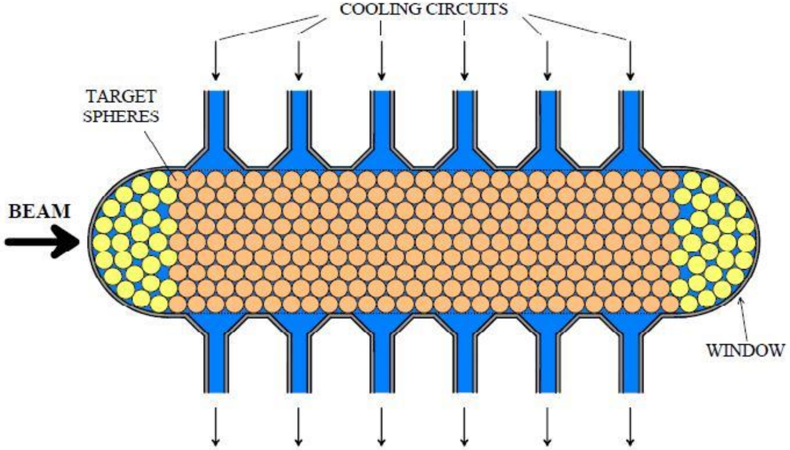
Carbon target



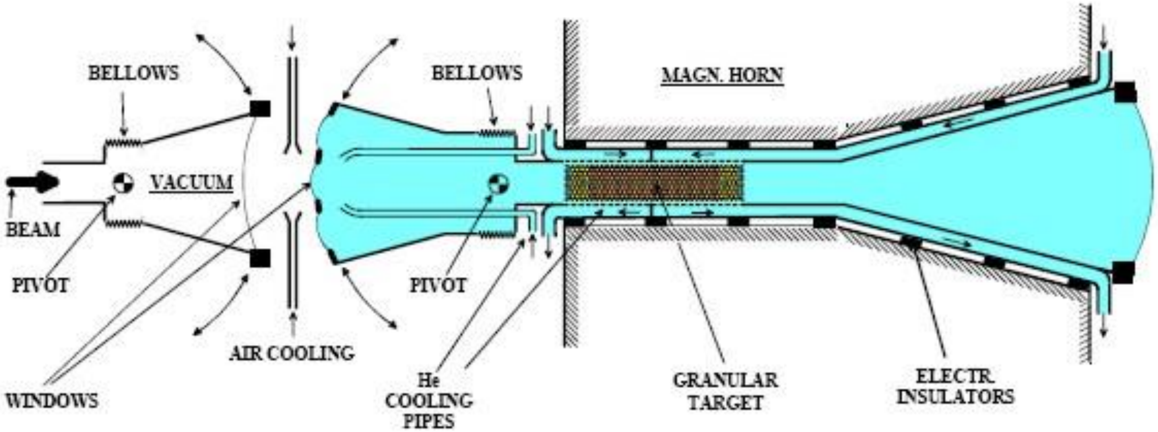
Pencil-like beryllium target (RAL)

Target cooling is a major issue

P. Sievers's proposal of a granular target at CERN (2001)



Cooling medium: water or gas helium



Concept of target integration inside a magnetic horn

P. Sievers's proposal of a granular target at CERN (2001)

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Main conclusions (P. Sievers „A Stationary Target for the CERN-Neutrino-Factory", CERN-NuFact-Note 065):

- Efficient heat removal and low dynamic stresses and pressures are achieved, mainly due to the small size in millimetre range of the target constituents in combination with relatively long proton bursts of several micro-second duration

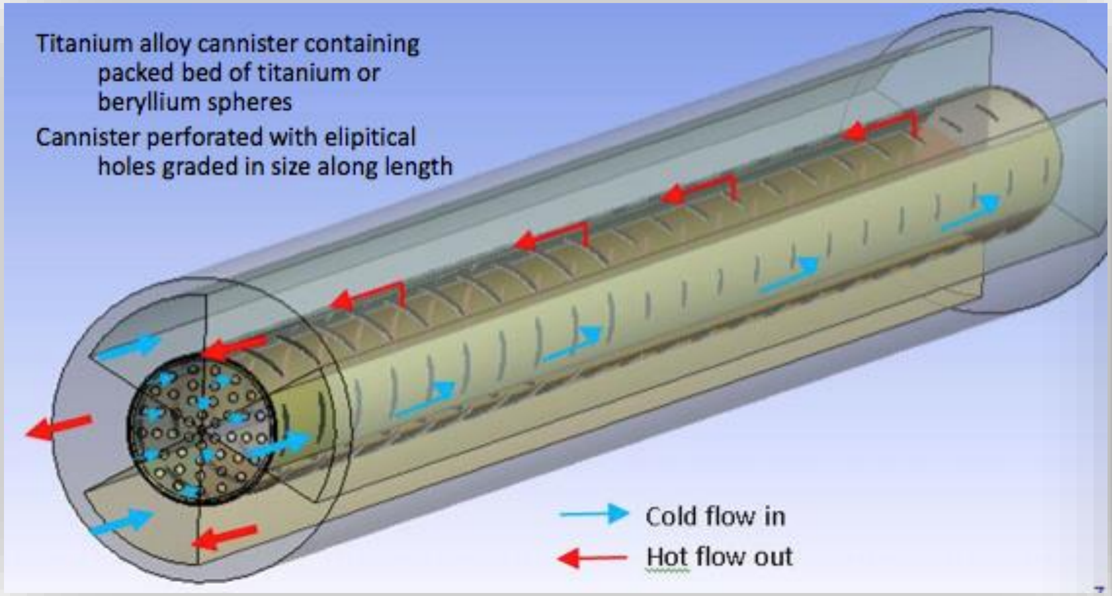
- Further computational and experimental studies of the performance limits must be investigated

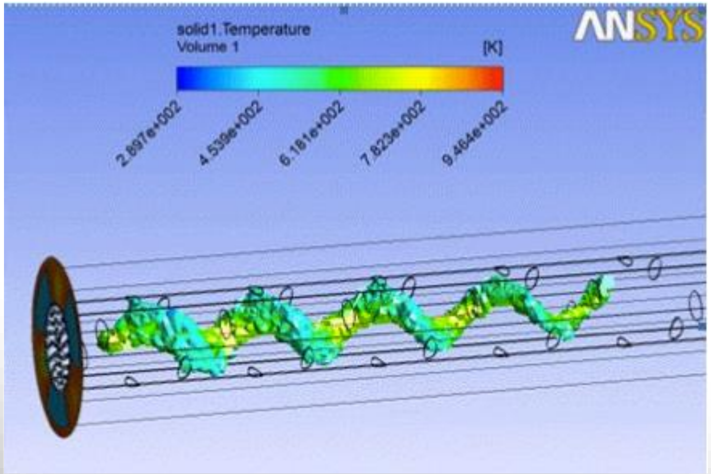
- These studies must include detailed considerations of the lifetime, due to the fatigue induced by the very high rate of the cycles per day, of the target spheres and, in particular, the entrance and exit windows

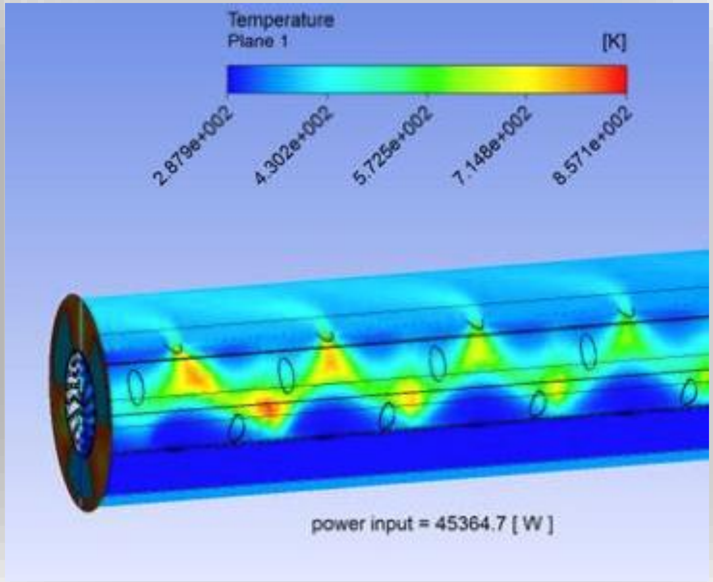
- Dedicated laboratory tests without the need of a proton beam should be devised to elucidate these problems

Packed-bed target studies at RAL

Packed-bed (pebble-bed) target, studied at RAL within the EUROν project







Some packed-bed target results at RAL (Tristan Davenne/RAL)

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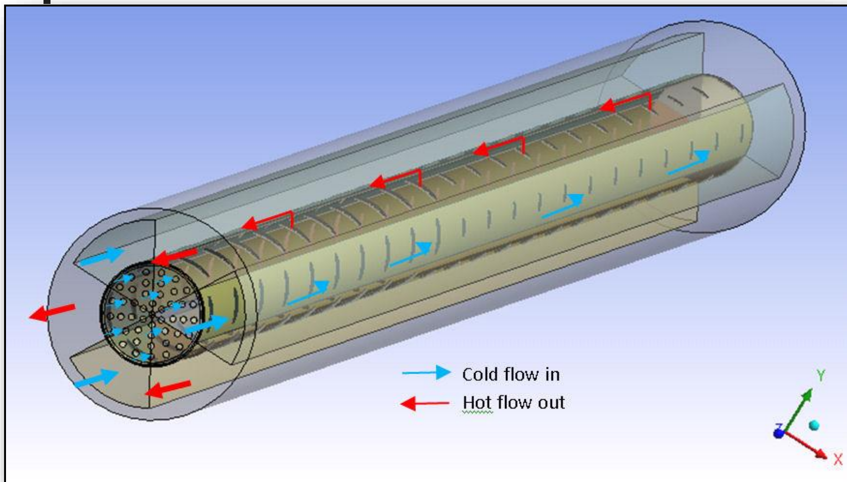


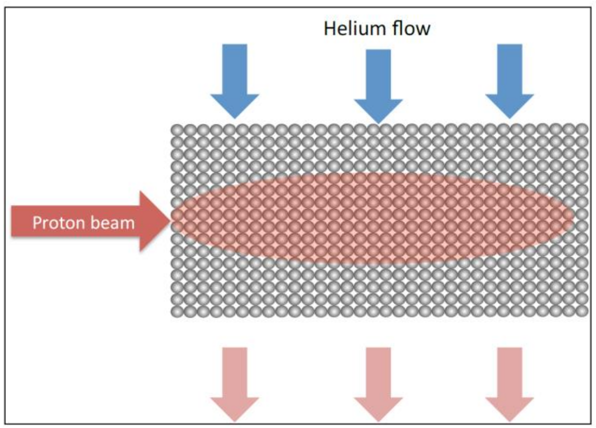
Model Parameters

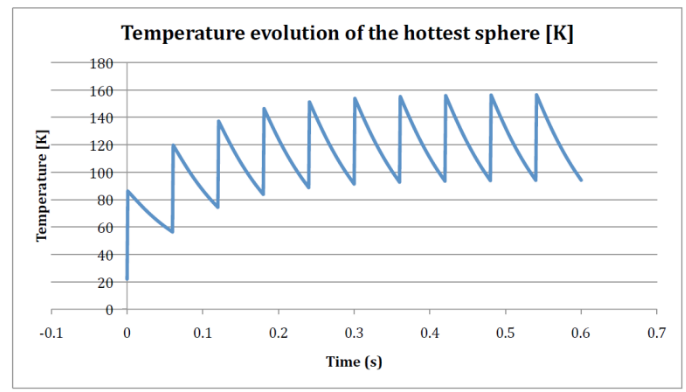
Proton Beam Energy = 4.5GeV
Beam Power = 1MW
Beam sigma = 4mm
Packed Bed radius = 12mm
Packed Bed Length = 780mm
Packed Bed sphere diameter = 3mm
Packed Bed sphere material : Titanium
Coolant = Helium at 10 bar pressure

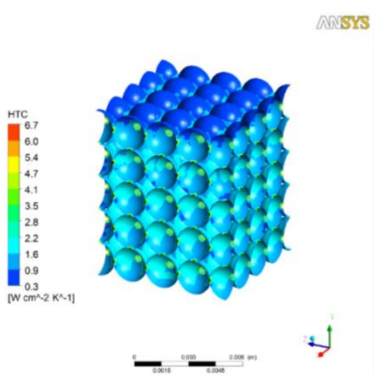
INPUTS								LIMITING FACTORS				
Beam Energy	Beam Sigma	Target Width	Beam Power	Sphere material	Sphere diameter	Helium pressure	Maximum Power Deposition	Maximum Helium Temperature	Sphere Core Temperature	Max Sphere VM Stress	Minimum Yield Stress / VM Stress	Pressure Drop
4.5 GeV	4mm	24mm	1MW	Ti6Al4V	3mm	10bar	2.2e9W/m3	133°C	296°C	49MPa	11.7	0.45bar
4.5 GeV	4mm	24mm	1.3MW	Ti6Al4V	3mm	10bar	2.9e9W/m3	133°C	331°C	65MPa	8.7	0.73bar
4.5 GeV	4mm	24mm	4MW	Ti6Al4V	3mm	10bar	8.8e9W/m3	200°C	650°C	116MPa	3.8	2.8bar
4.5 GeV	4mm	24mm	4MW	Ti6Al4V	3mm	20bar	8.8e9W/m3	133°C	557°C	140MPa	3.2	3.4bar
4.5 GeV	4mm	24mm	4MW	Ti6Al4V	3mm	20bar	8.8e9W/m3	200°C	650°C	116MPa	3.8	1.4bar

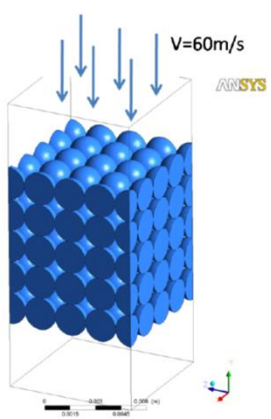
Pebble-bed target studies at ESS

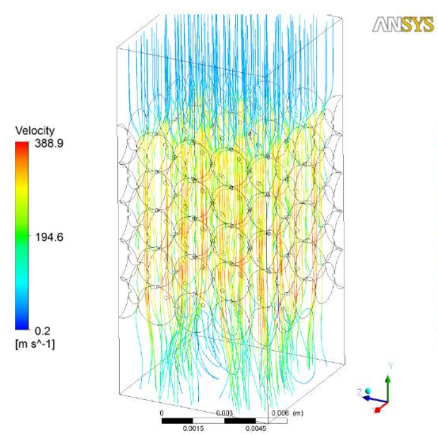
Some results by C.Kharoua and E.Noah of ESS

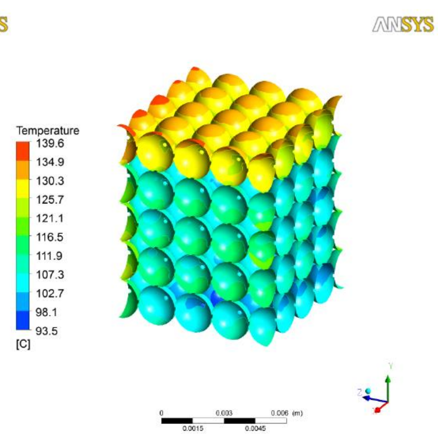












Target studies currently underway

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- The analysis of the vibrations of the spheres
- Dynamic thermal stress levels in the spheres
- Fatigue life estimate of the spheres
- Target cooling issues
- Environmental effects (radiation damage, cavitation, etc.)
- Technical challenges: materials

Several target issues

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Concerning the He-cooled systems:

- Tritium production from the small amounts of He-3 (at the ppm level) contained in natural He
- Cleaning of He circuits
- He leak-tightness

Some material issues for the spheres:

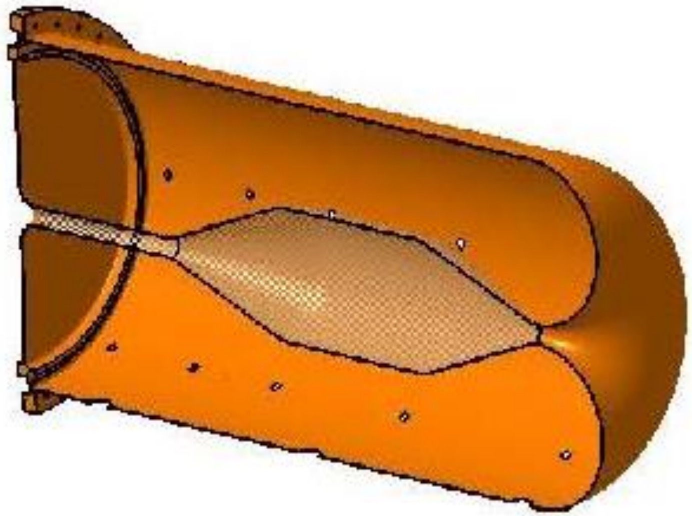
- Material properties of irradiated titanium operated as a He-cooled target need more consideration
- The cyclic thermal load and the use of He at a high pressure as a coolant call for better understanding. Surface imperfections can be sites of crack initiation, leading eventually to fracture
- Surface erosion can result in the activated titanium dust being carried away in the He stream

Such materials issues are often overlooked at the CDR stage; showstoppers often come from materials issues under these severe loading conditions (dynamic thermal load, irradiation, chemistry).

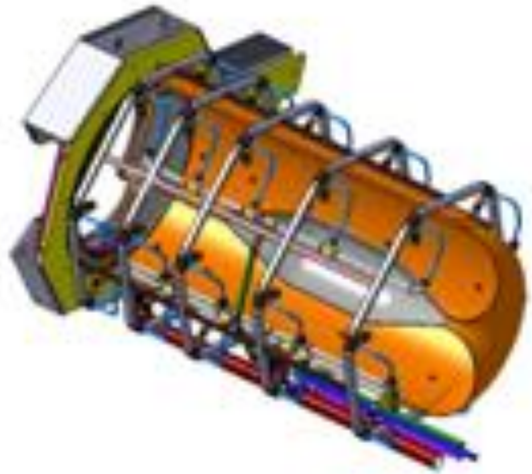
Horn design

Design : MiniBooNe-like Horn
Material : Aluminum Al T 6061 – T6
Geometry : Length 2.4 m, diameter 1.2 m
Inner/Outer conductor thickness : 3 mm /10 mm
Peak Current : 350 kA

=> Concept will be upgraded for ESSνSB



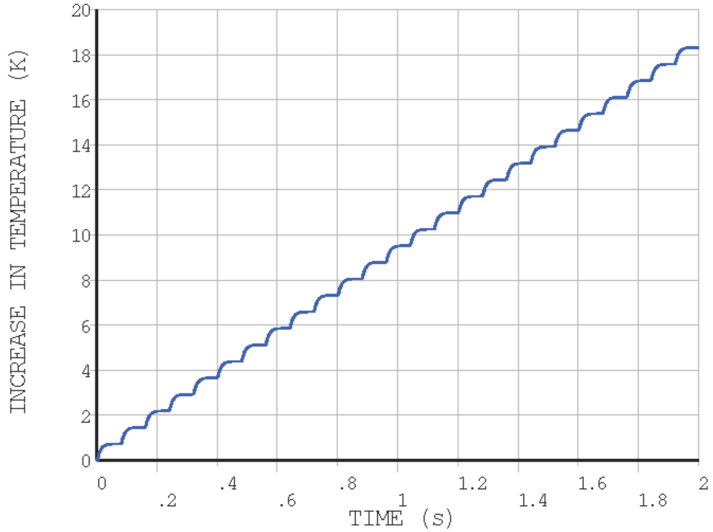
Horn cooling by water spray



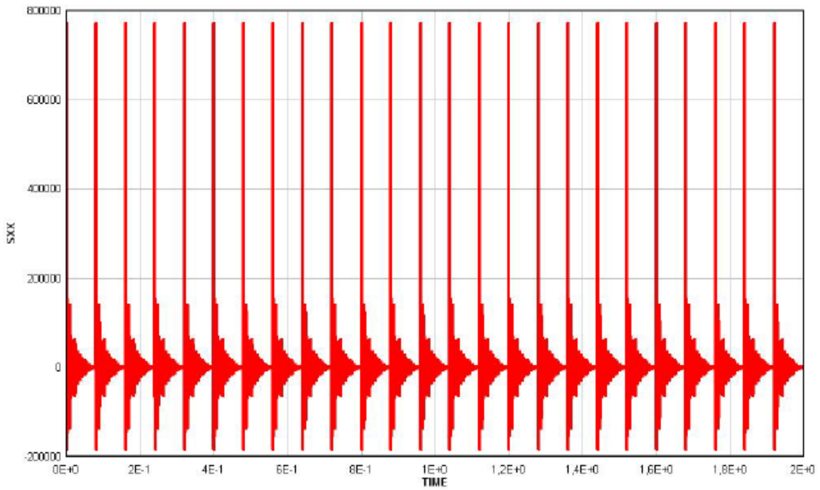
Dynamic response under a sequence of current pulses

Dynamic response to a sequence of 25 pulses, each of 100 μs duration; the pulse repetition rate was 12.5 Hz (EUROν's conditions)

Rise in temperature



One stress component (in MPa)



Such results can be used to estimate the fatigue life of the horn

Horn studies underway

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Horn design issues

- Optimization of the horn geometry for the ESSνSB conditions
- Steady-state temperature analysis and the resulting static stress
- Dynamic stress due to short-duration pulses
- Assessment of the longevity (fatigue life) of the horn and its auxiliaries
- Vibration transmission from the horn to the cooling piping
- The performance of the cooling system (is it possible to apply heat exchange theory to predict the performance of the cooling system in agreement with the existing experimental data?)

Target station power supply (studies at CNRS for the EUROν project)

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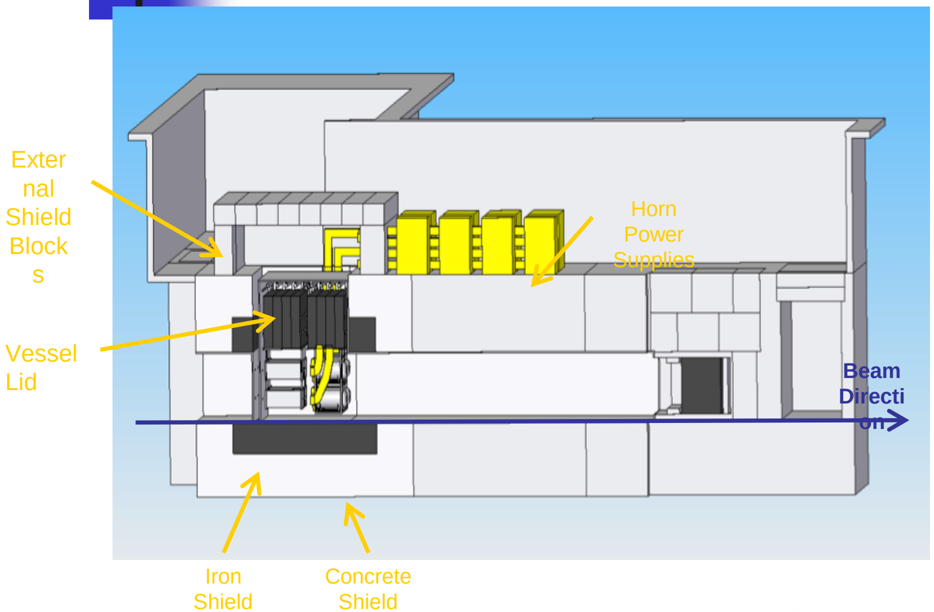
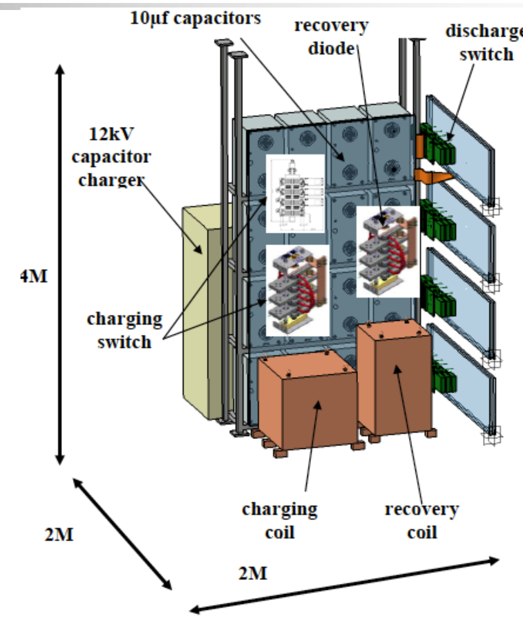
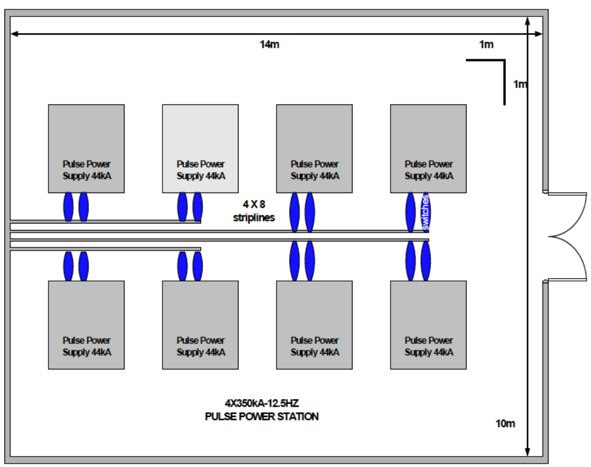
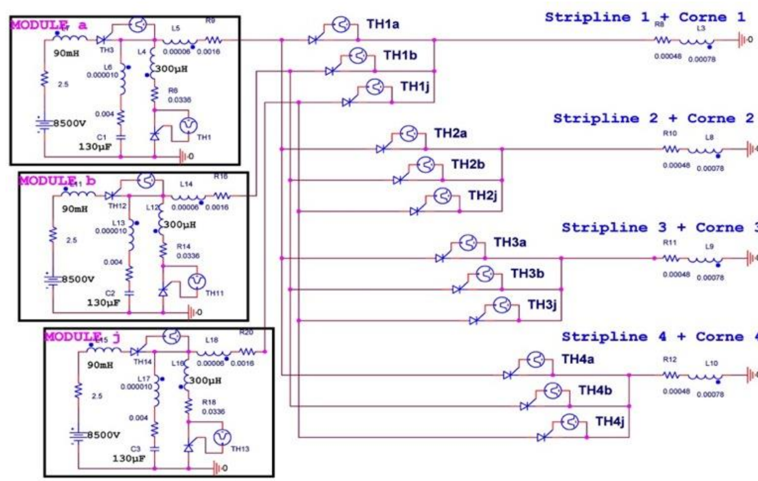


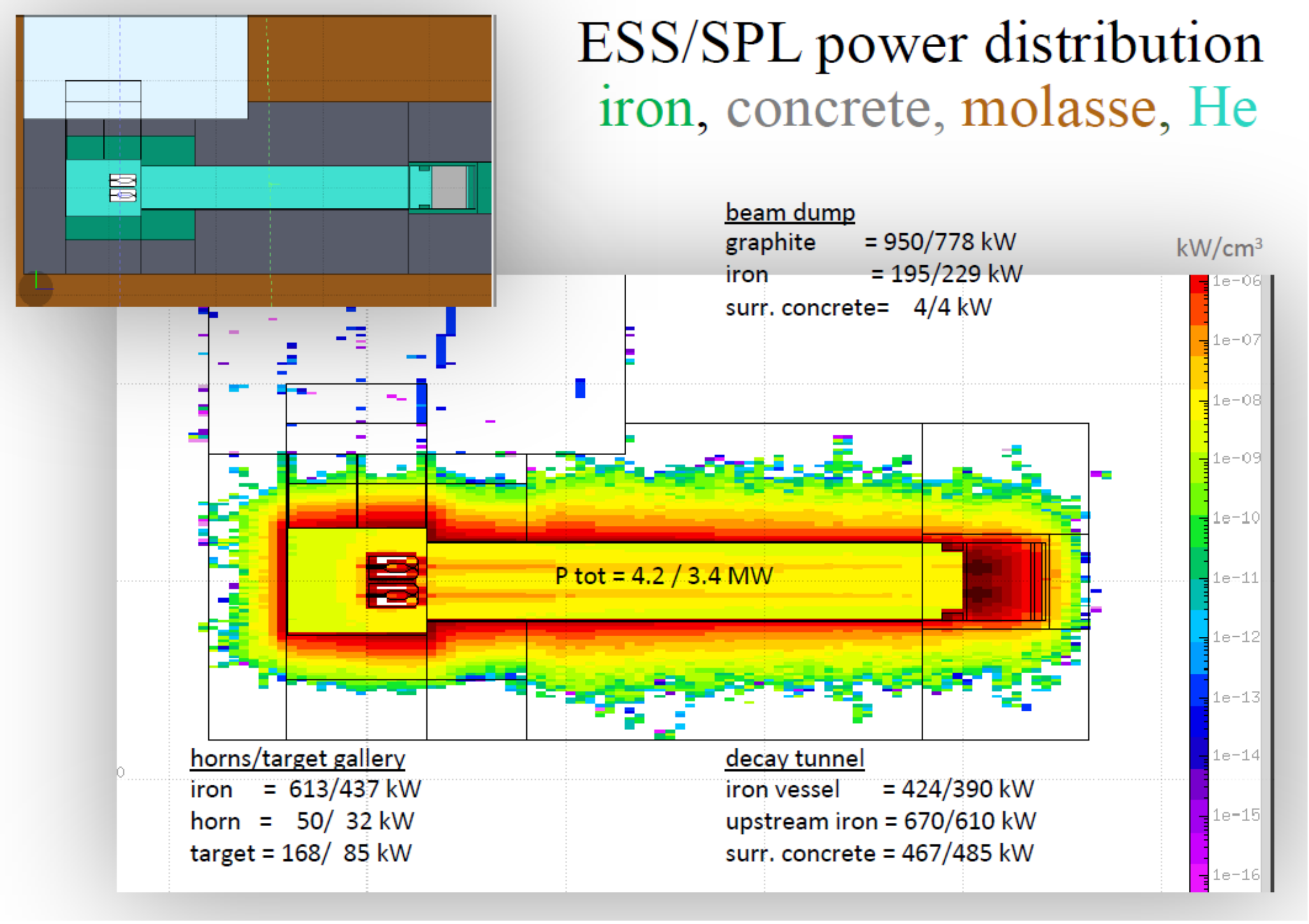




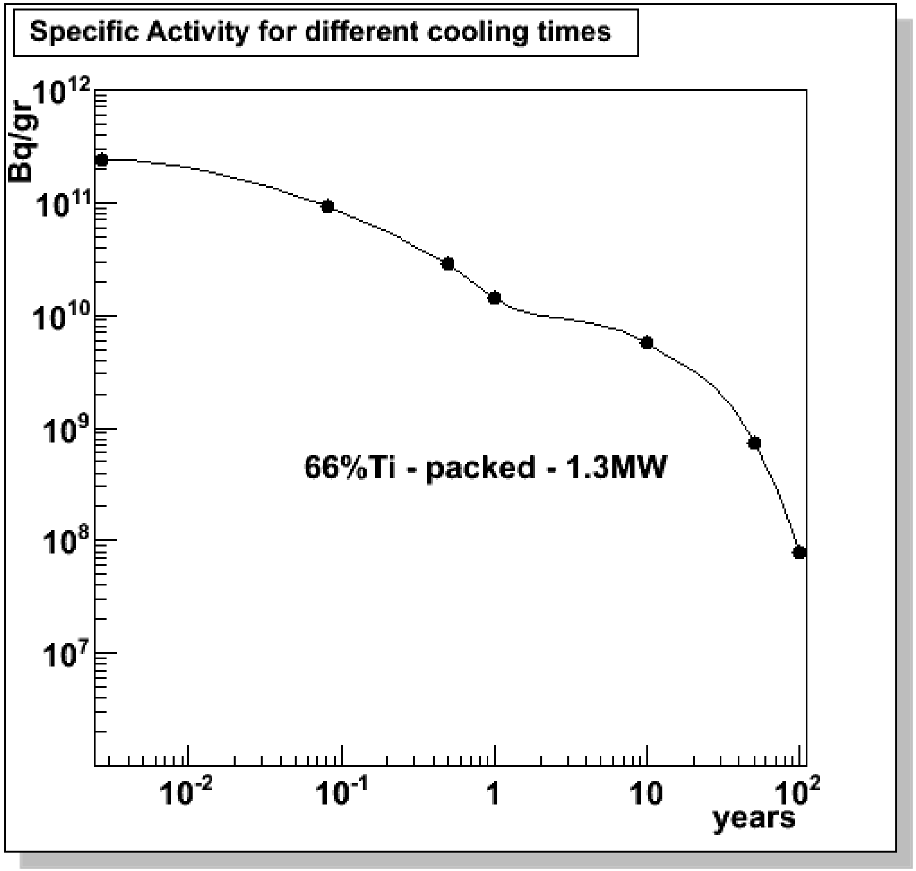


- each MODULE delivers a current of 44kA max at F=50HZ
- For each HORN : current of 350kA max at 12.5HZ
- energy recuperation (>90%) and reinjection
- lifetime > 13 Bcycles (10 years, 200 days/year)

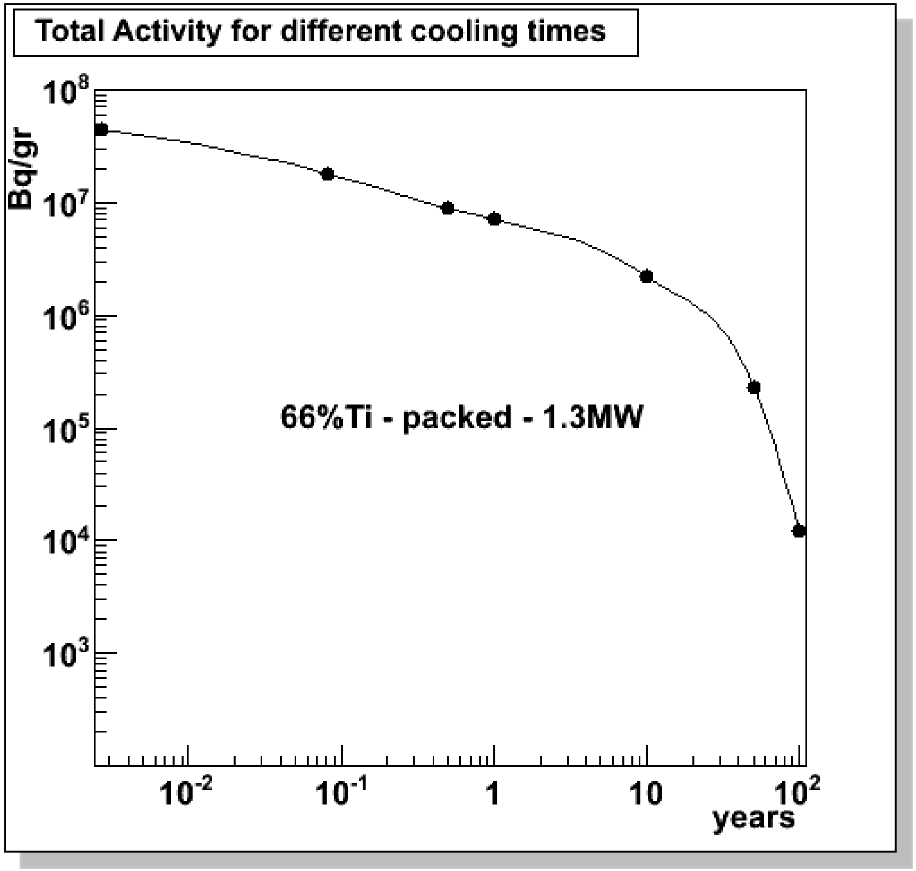
Energy deposition in the target station



Material activation

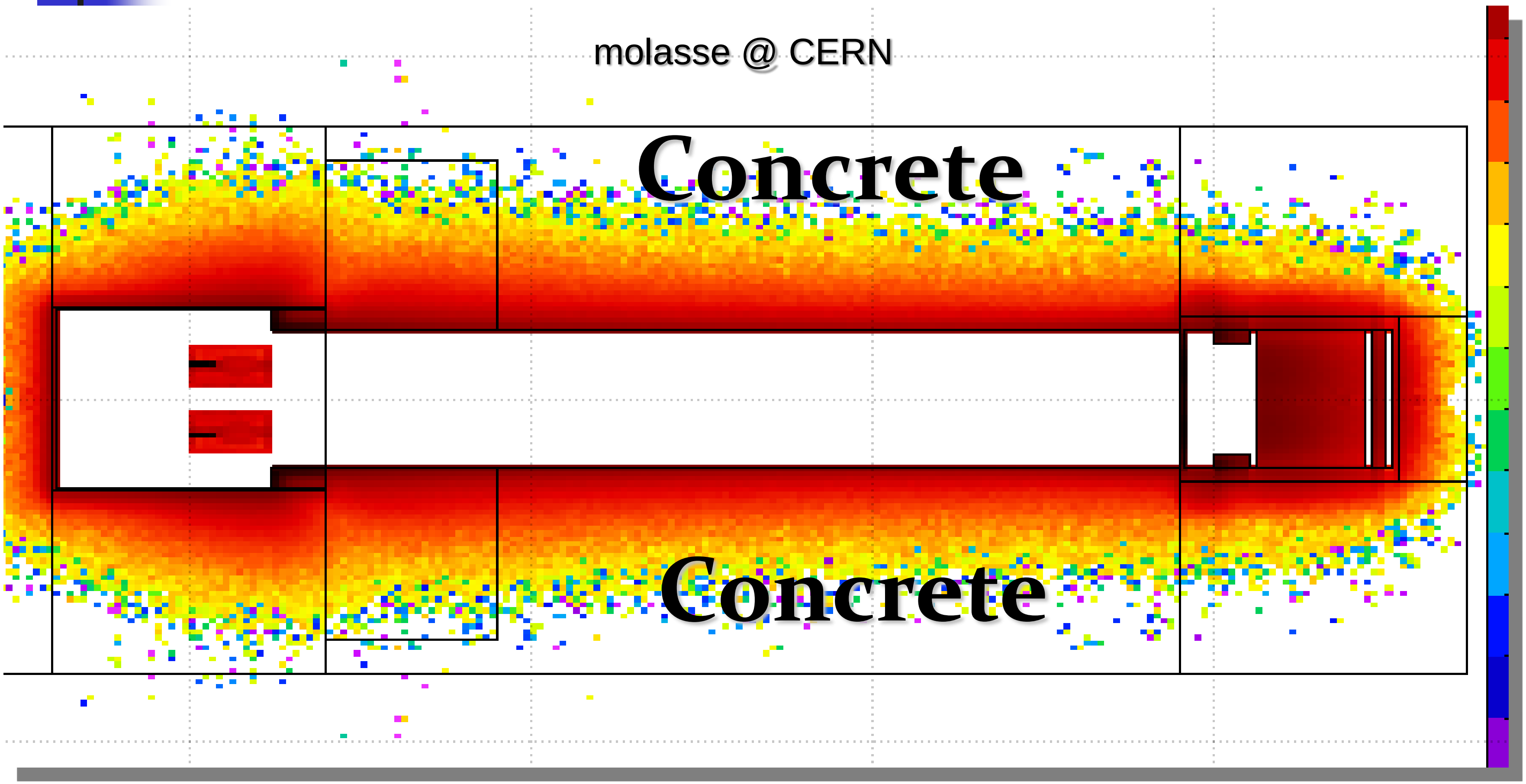


Target



Horn

Environmental impact



A 6m thickness concrete wall surrounding all the layout limits the production of radionucleides in the molasse. Especially, the production of ^{22} Na and tritium could represent a negative impact by contaminating the ground water.

Summary

- The ESSνSB Design Study is now into its first realization year
- The project draws on the previous experience: on the EUROν project for the target station, and LAGUNA for detectors
- The high-power targetry issues constitute an important part of this design study
- Work is now underway on all aspects that are pertinent to this design study (only a small part of the activities has been reviewed)