ESS NEUTRINO SUPER BEAM

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Status of the ESSvSB Target Station

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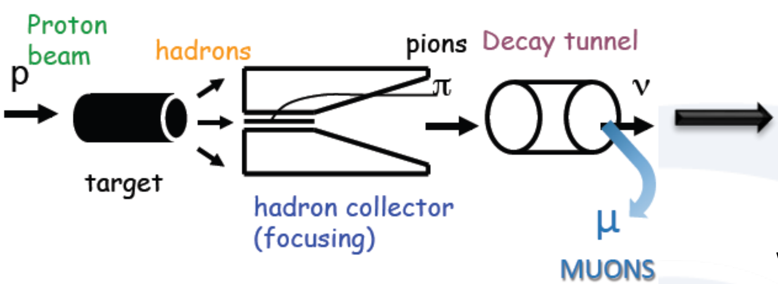
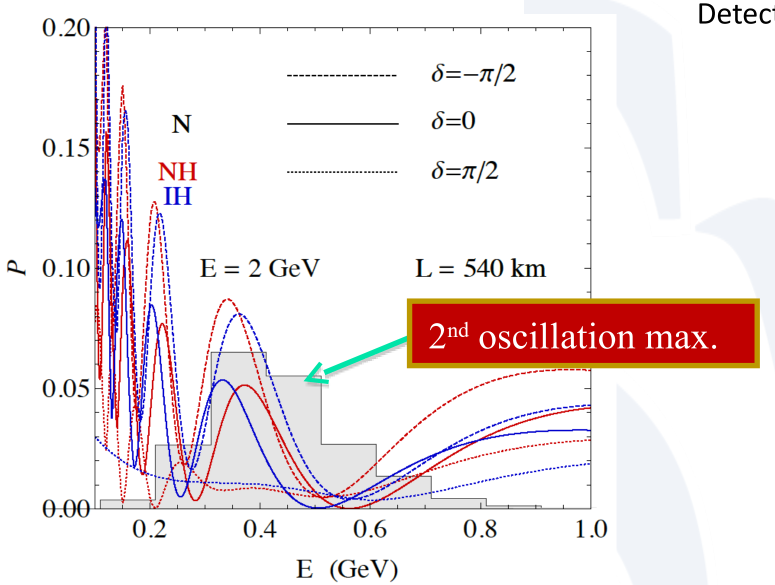
on behalf of the ESSvSB Project Target Station Working Group (WP4)

Presentation outline

- ESSvSB experiment
- Target Station overview and beam parameters
- Horn power supply
- Power deposition and cooling
  - Granular Target
  - Magnetic Horn
  - Beam Dump
- Horn optimization (Genetic Algorithm)
- Summary

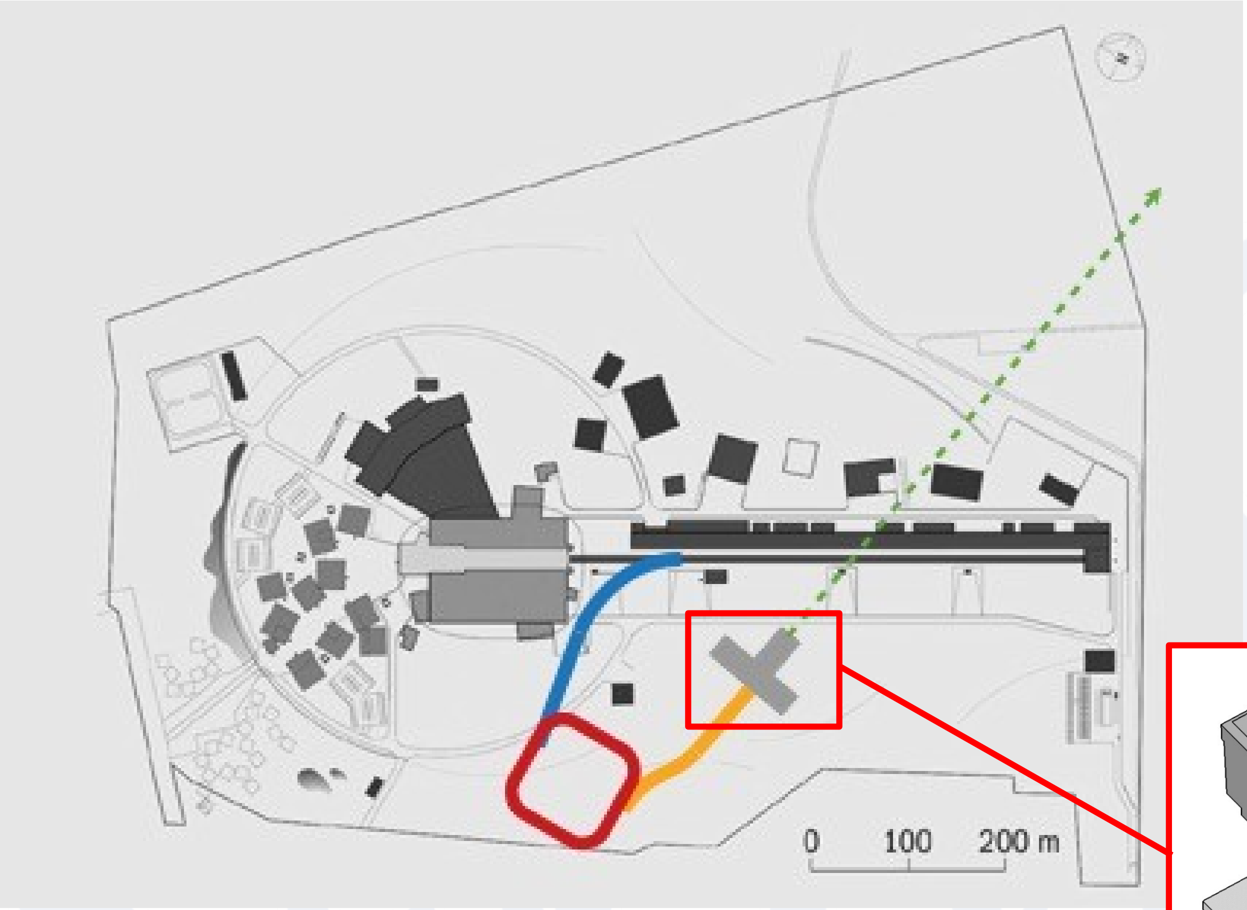
ESSνSB experiment



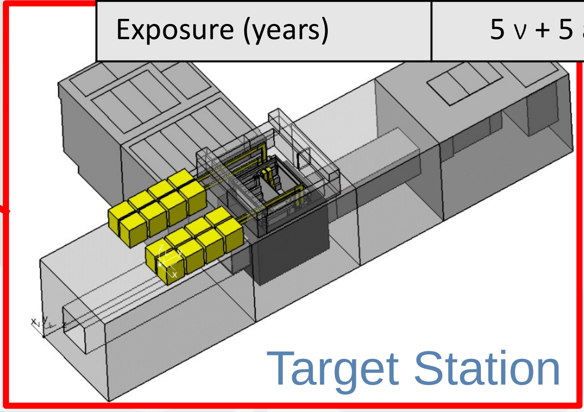


The far water Cherenkov detector will be placed at the second oscillation maximum, at the Garpenberg mine, 540 km from Lund.

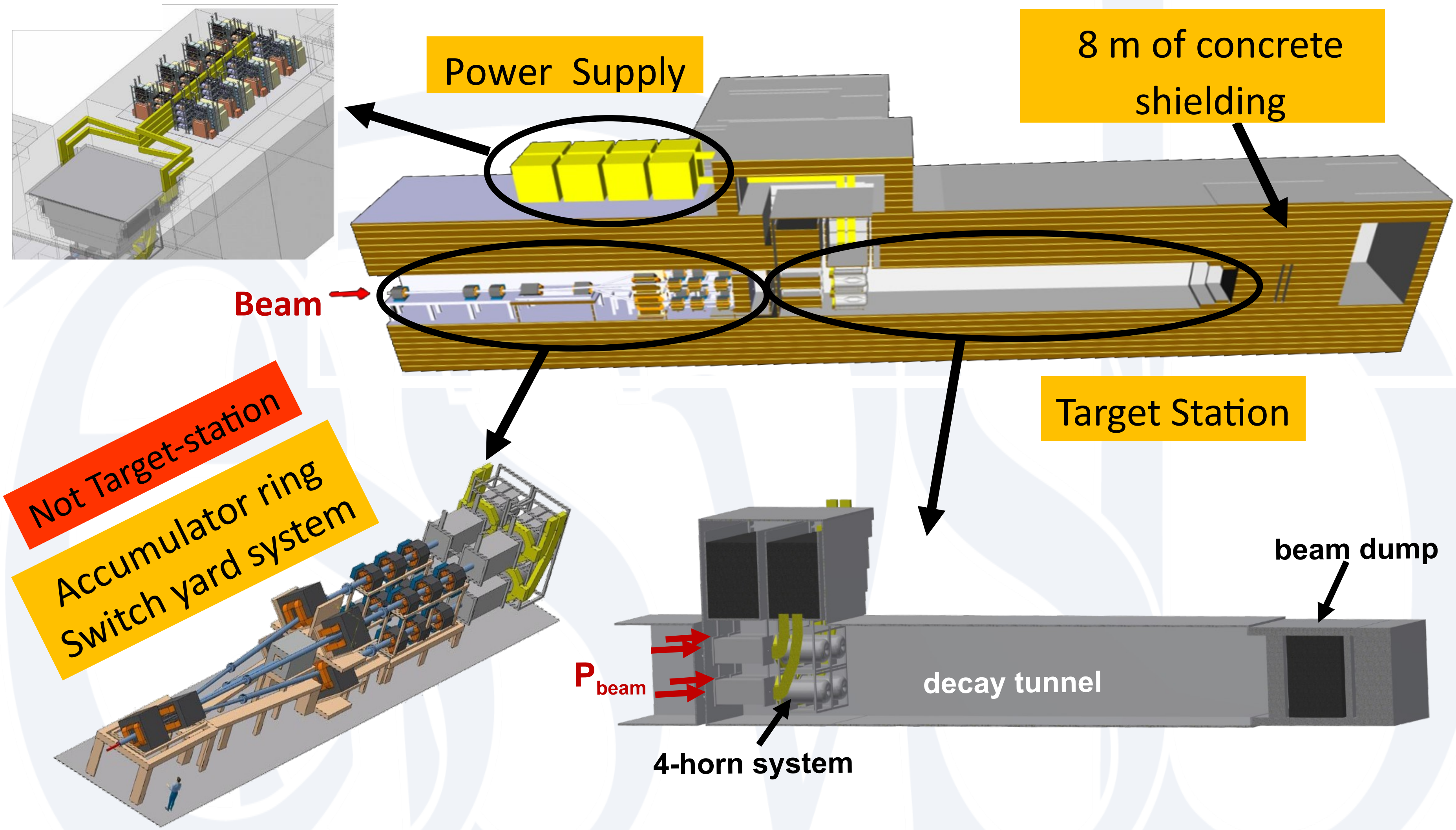
ESSνSB Target Station facility and baseline parameters



Parameter	ESSνSB
Power (MW)	5
E_{p+} (GeV)	2.5
Baseline (km)	540
Target	packed-bed
Target length (cm)	78
Target radius (cm)	1.5
Horn	forward closed
Horn current (kA)	350 @ 14 Hz
# of horns/targets	4
Tunnel length (m)	25
Tunnel size (m x m)	4 x 4
Exposure (years)	5 ν + 5 anti-ν

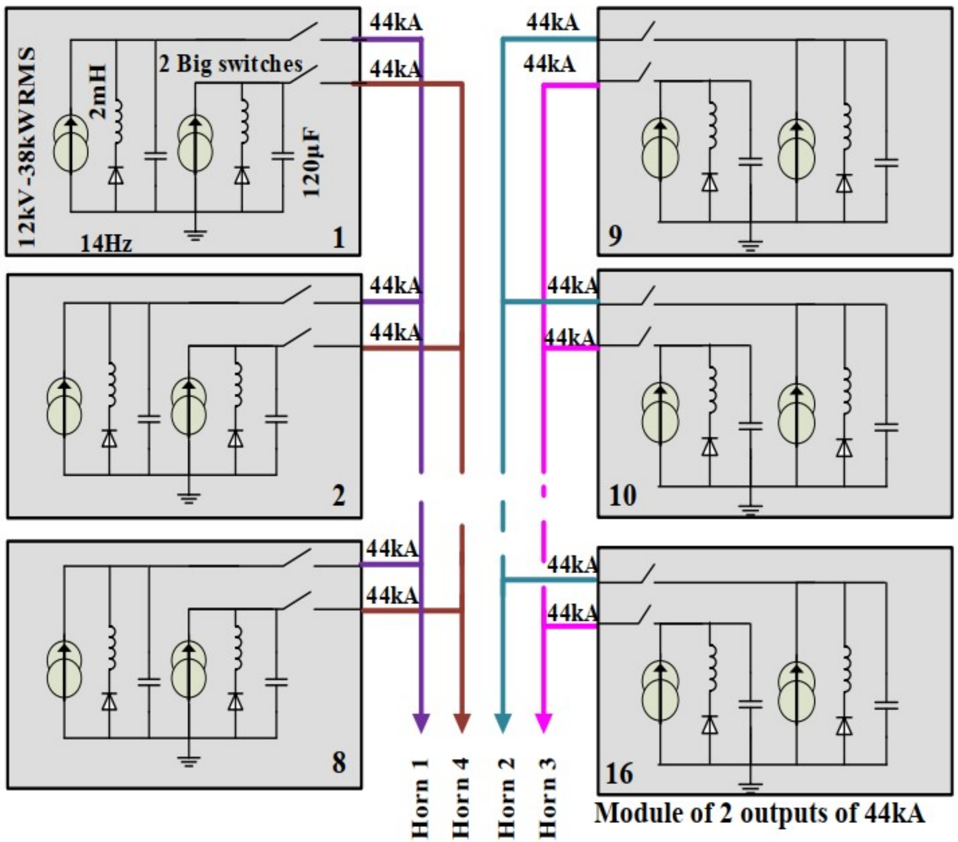


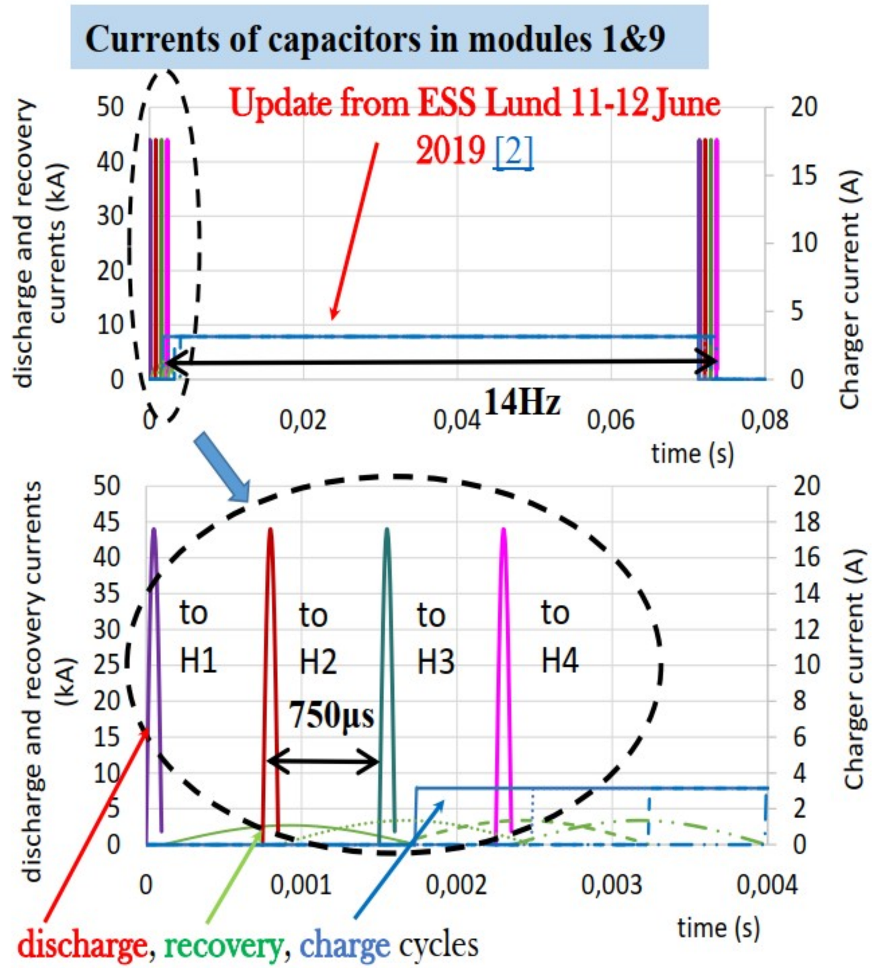
Layout of the target station facility



Horn power supply: modular approach

Modular Approach:



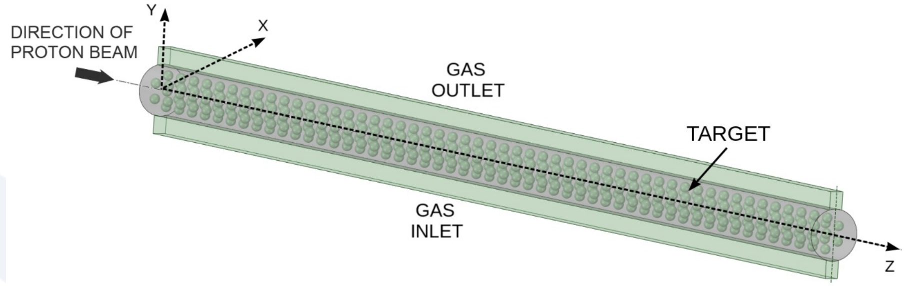


- **8 modules of 44kA** connected in parallel to provide 350kA to 1 horn.
- 16 modules needed for 4 horns

P. Poussot

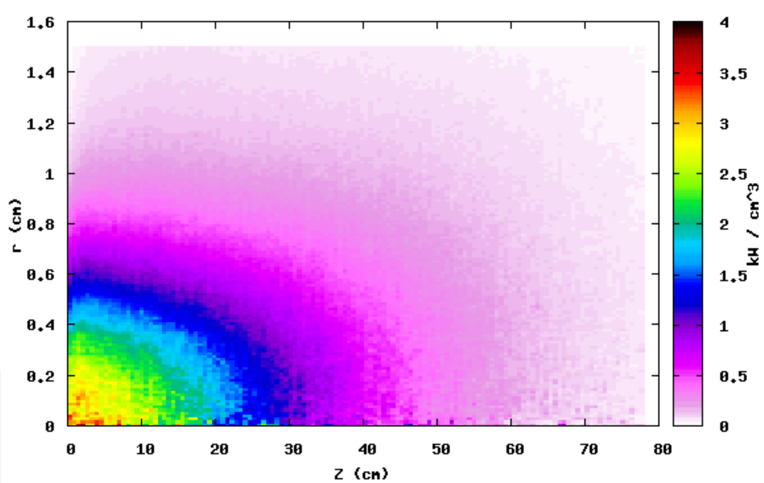
Power deposition and heat transfer inside the target

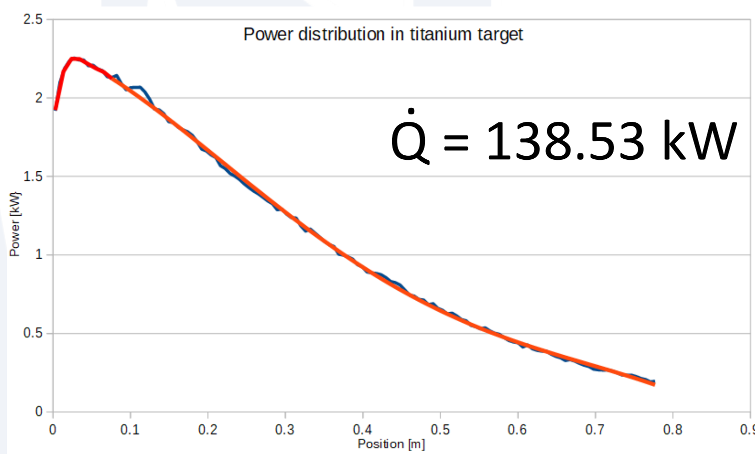
Two stages of heat transfer (occuring in parallel):
beam → spheres → helium (coolant)



Main assumptions:

- Full transfer of energy from the beam to the spheres happens during a very short finite time at the beginning of each cycle
- The only form of heat transfer between the spheres and the flowing gas (helium) is by forced heat convection, as the helium is forcibly pushed through the target; radiation is considered as negligible
- Heat flux between the surface of the spheres and the cooling gas is proportional to the temperature difference and heat transfer coefficient h [W/m²K]





$\dot{Q} = 138.53$ kW

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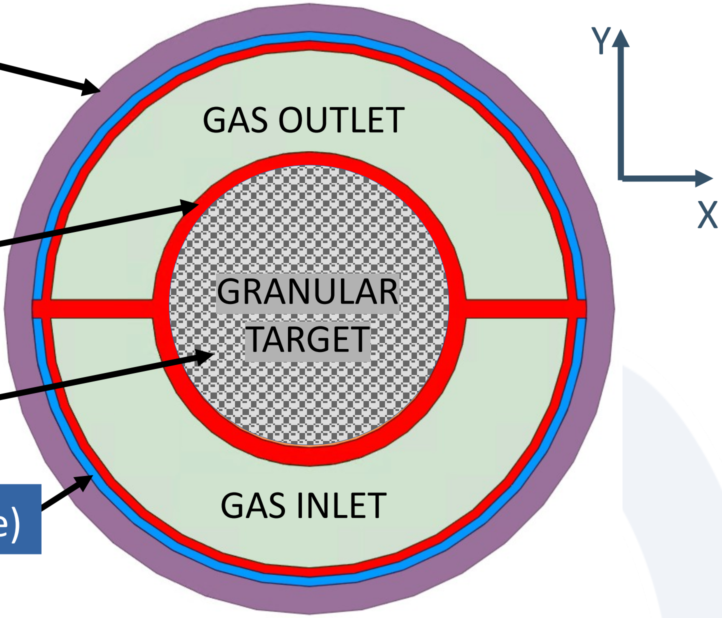
Horn-target integration shell design

HORN (part closest to target), aluminium
Constant $p_d = 3.92 \times 10^7$ W/m^3
Heat transfer coef. on outer surface $h = 3000$ W/(m^{2}K)

SHELL, titanium
(2 mm thickness, 1mm close to insulation)

GRANULAR TARGET, titanium spheres
(3 mm diameter)

INSULATION (1 mm helium space)



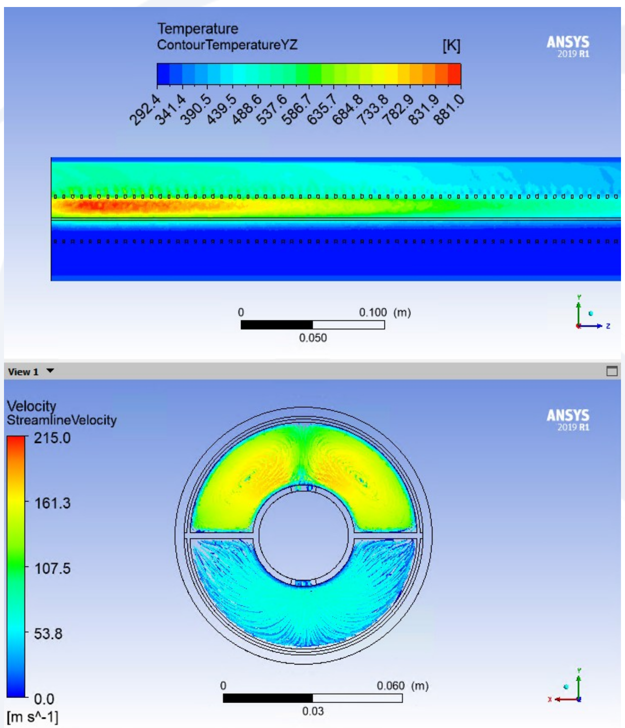
Hole length proportional to power in given cut-out section, width w=1.5 mm, 128 holes every 780/128 mm

Total hole are is twice the size of the inlet/outlet shell area

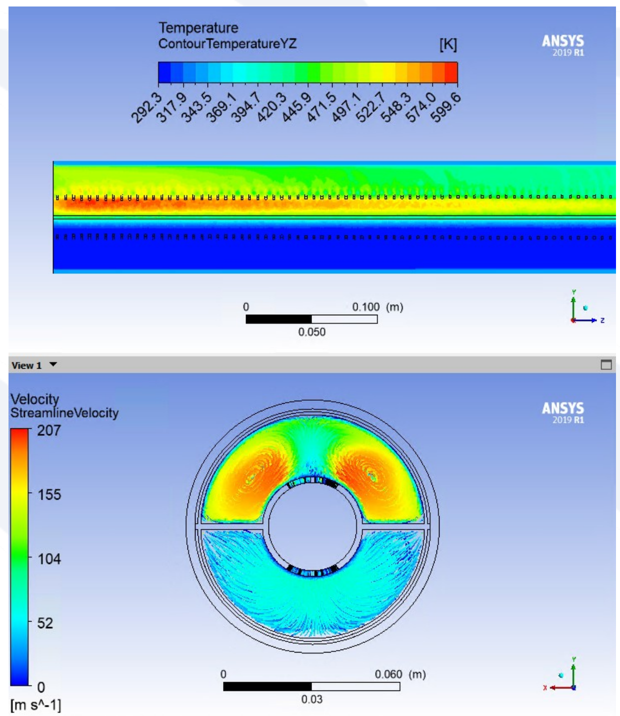
Target cooling

(titanium spheres, Q' = 138.53 kW, m'=0.2 kg/s), inner horn diameter d = 80 mm

holes of identical length



holes of length proportional to power deposited in given section



Similar calculations performed also for inner horn diameter d = 60 mm and for different materials (with corresponding power distribution):

- graphite
- beryllium
- tungsten

Target bending due to thermal gradient is being studied, however the preliminary results show it to be within an acceptable range.

Shell support needs to be designed to reduce the bending.

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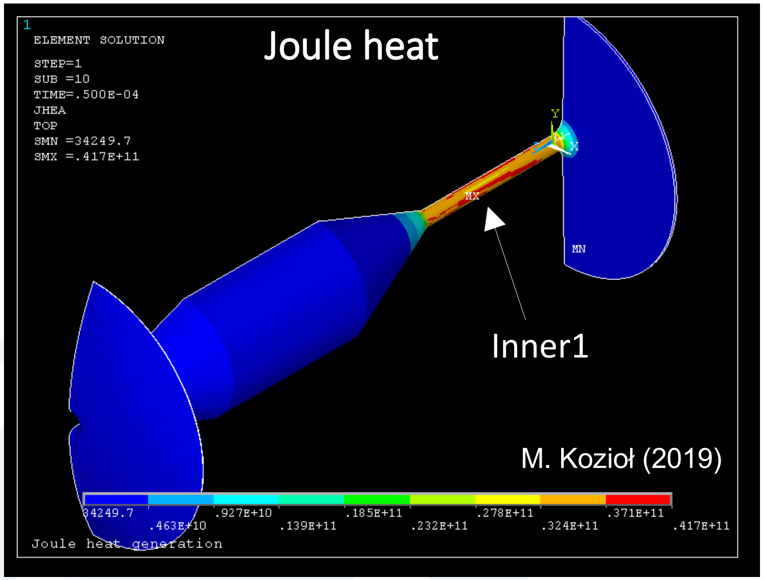
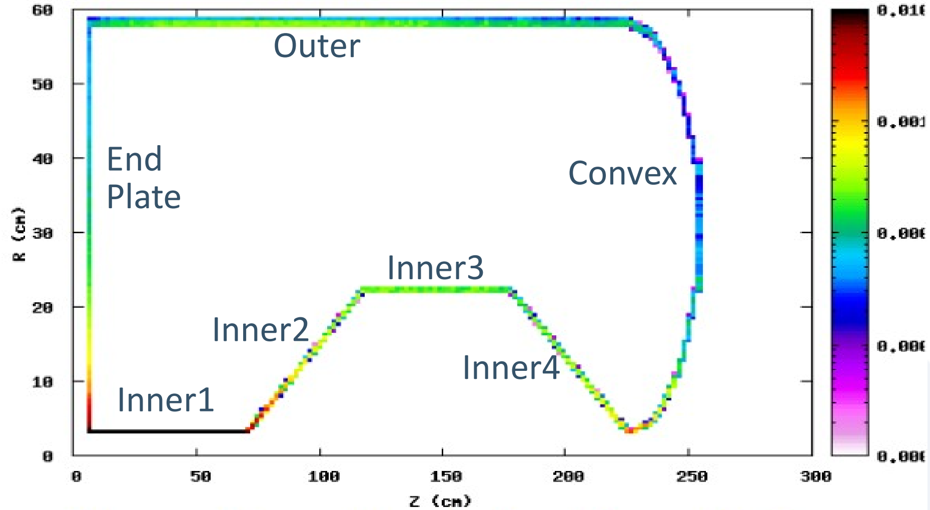
Horn power deposition (Joule heating + secondary particles)



Secondary particles

Loris D'Alessi (2020)

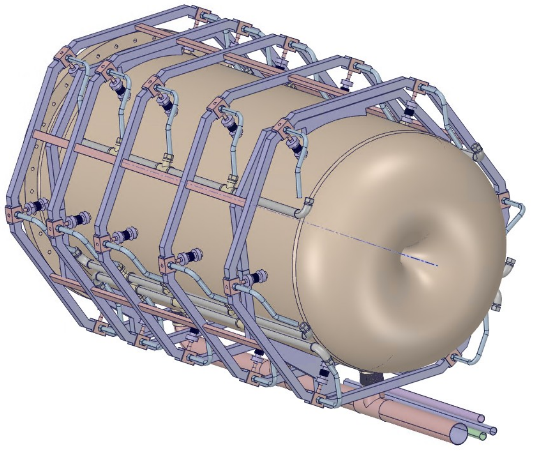


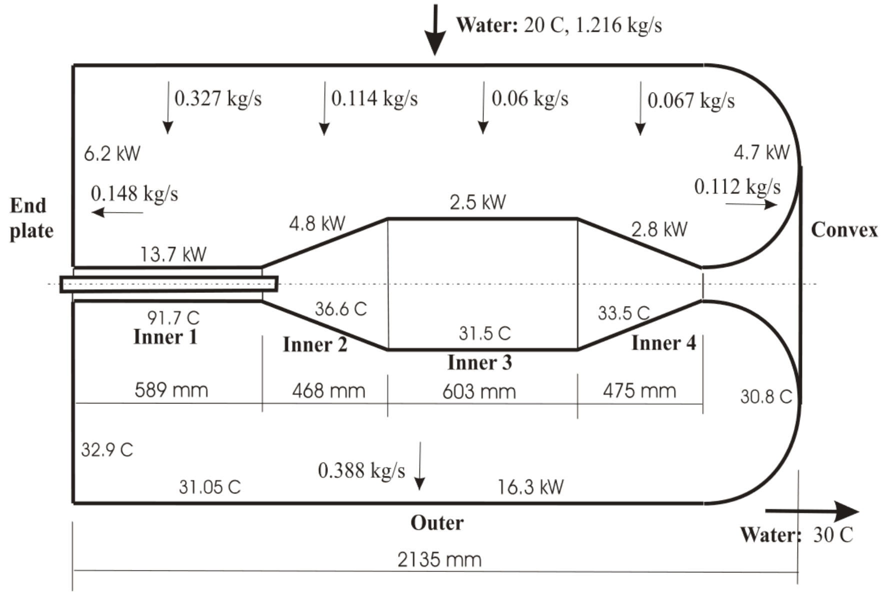
Energy Deposition in the Magnetic Horn

	End Plate [kW]	Inner1 [kW]	Inner2 [kW]	Inner3 [kW]	Inner4 [kW]	Convex [kW]	Outer [kW]	Total [kW]
Secondary Particles	5.0	7.5	3.1	1.6	1.1	2.5	15.0	35.8
Joule Heat	1.2	6.2	1.7	0.9	1.7	2.2	1.3	15.2
Total	6.2	13.7	4.8	2.5	2.8	4.7	16.3	51.0

Horn cooling by water jets

- The calculation of temperature and corresponding necessary water flow were performed based on the provided map of heat power introduced to the selected parts of the horn due to the effect of the beam on the target (secondary particles) and the flow of electricity through the horn (Joule heat losses).
- Heat flow rate between the surface of the section and the cooling medium (water) is proportional to the temperature difference between them and the convection coefficient.
- The transmission of heat occurs only due to the convection from the hot surface of the section to the flowing water





Numerical analysis results

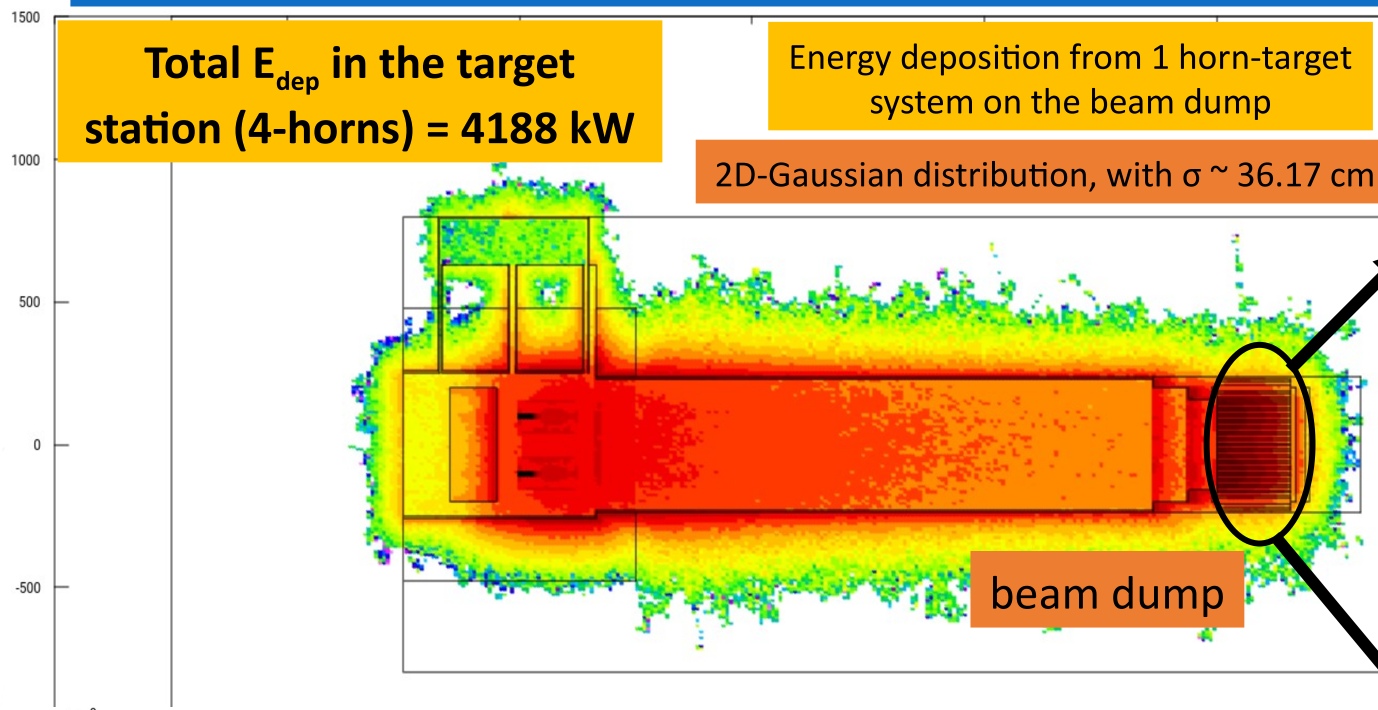
	h [W/(m² K)]	Max Temp. [°C] (at Inner1)
Cooling 1	2000	77.1
Cooling 2	3000	58.4

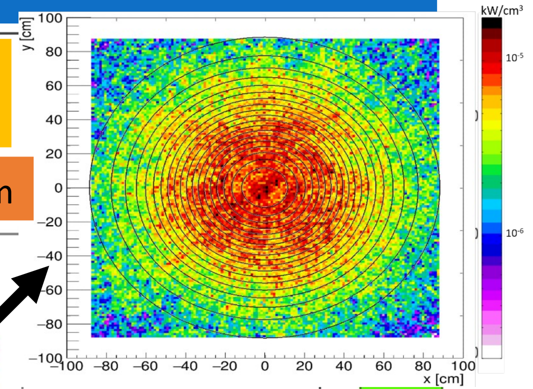
ESSvSB beam dump

Total E_{dep} in the target station (4-horns) = 4188 kW

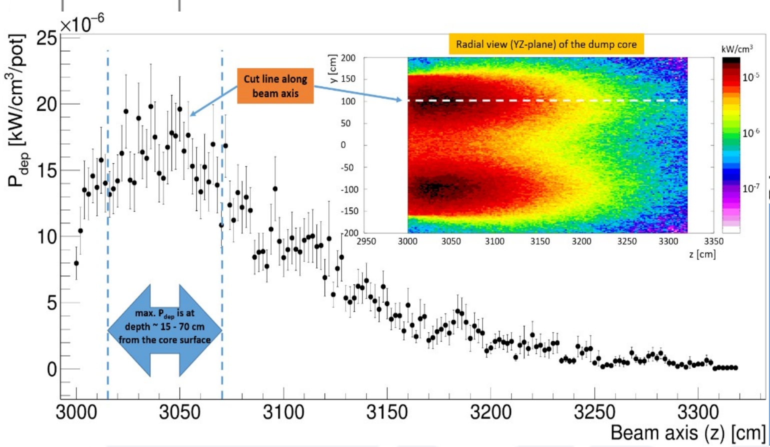
Energy deposition from 1 horn-target system on the beam dump

2D-Gaussian distribution, with σ ~ 36.17 cm



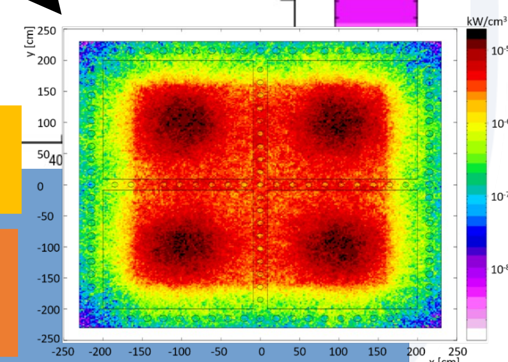


beam dump



Energy deposition from 4 horn-target systems on the beam dump

Total E_{dep} in the beam-dump (4-horns) = 826 kW



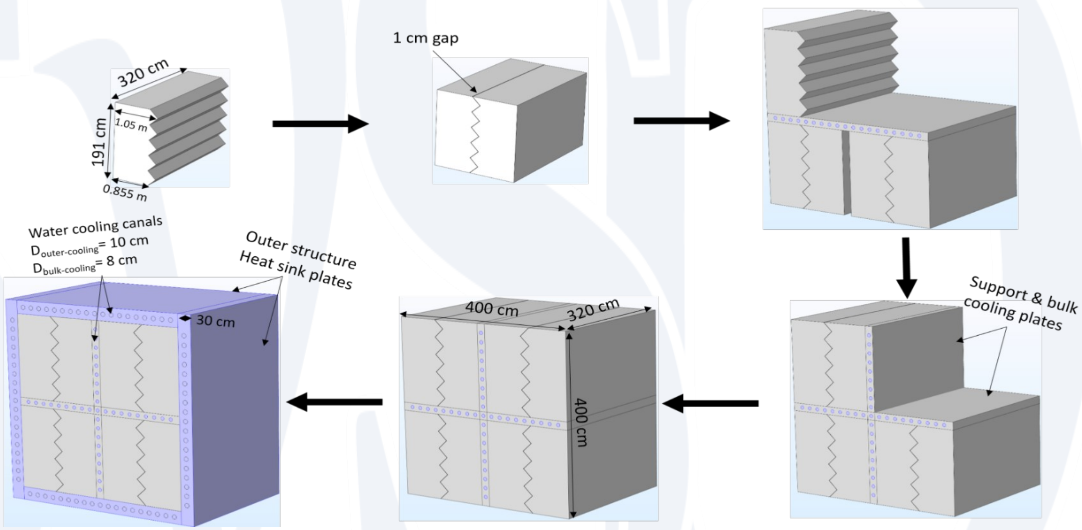
Beam dump (design concept)

Beam dump design requirements:

- Withstand the energy deposition from the 5 MW proton beam on the four targets.
- Offer maximum shielding for the underground site behind it from all secondary radiation.
- Being replaceable, whether for the whole structure or its individual parts.
- Different structure designs, with outer layout 4 x 4 x 3.2 m3.

Segmented-blocks dump core (baseline):

- four independent core blocks, segments.
- Each block faces one of the four horns.
- Each segment is constructed from two zigzag blocks with 1 cm opening between them, to allow for thermal expansion.
- Side and middle support structures to be used as heat sinks for structure cooling.
- Water-cooling with canals drilled in the support blocks.



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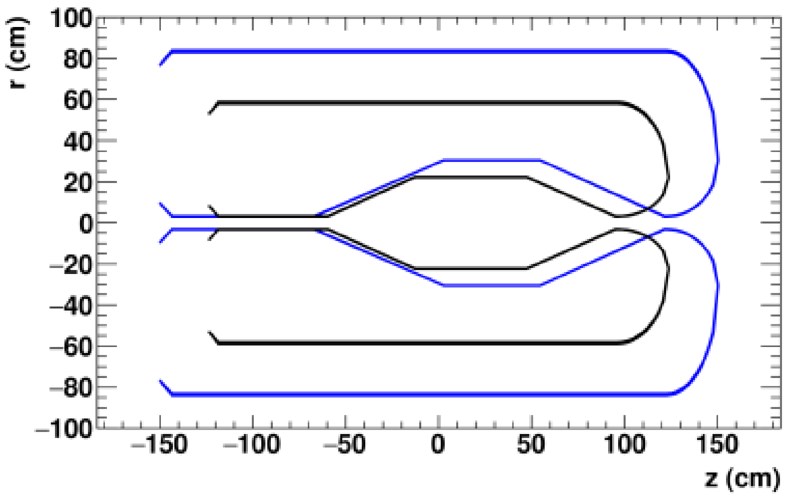
The GA applied to the design of the Target Station components

Study done by Loris D'Alessi

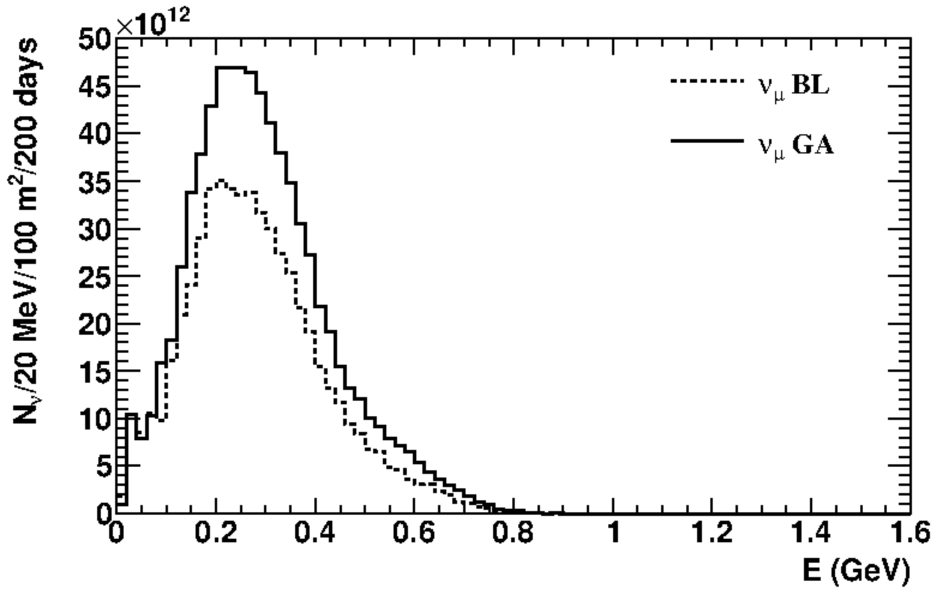
- All the results so far consider the baseline solution
- An effort has been made to optimize the target station for physics performance
- A Genetic Algorithm driven optimization has been developed for the design of the ESSvSB target station [1-2].
- The starting point of the Genetic Algorithm (GA) applied to the ESSvSB experiment is the current baseline of the Magnetic Horn (MH) and Decay Tunnel (DT) geometry.
- According to our results, a larger shape of the horn (with fine tuning of the parameters of the inner region of the horn) and longer decay tunnel lengths are preferred.

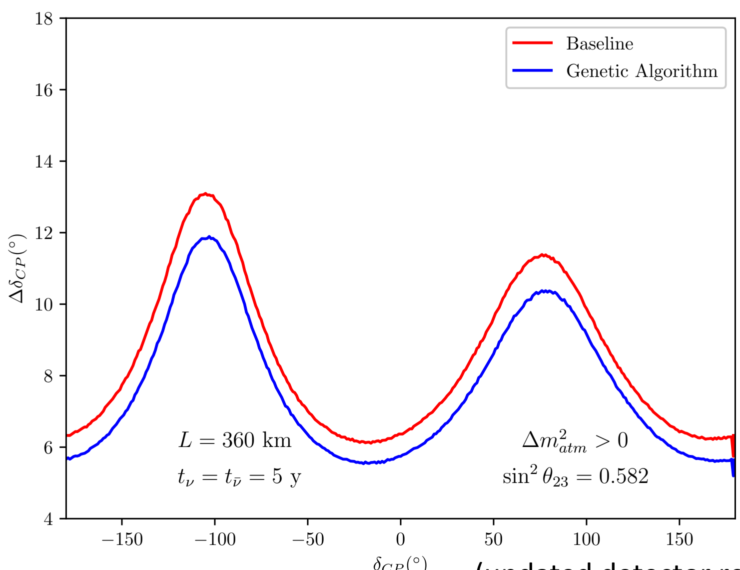


Presentations:
[1] L. D'Alessi *et al.* [ESSvSB], "Optimization of the Target Station for the ESSnSB Project Using the Genetic Algorithm", NeuTel Conference 2021.
[2] L. D'Alessi *et al.* [ESSvSB], "Neutrino Beam Optimization for the ESSnSB Experiment", International Research Network - Neutrino 2021.

The GA applied to the design of the Target Station components

- As a first consequence of the performance of the new 4horn/decay tunnel system, the statistics in the right sign neutrinos is improved [1].
- Furthermore, the sensitivity results improved as well
  [More information in: „Updated physics performance of the ESSnuSB experiment" (https://arxiv.org/abs/2107.07585)]
- Studies are currently on going to determine the feasibility of the horn geometry suggested by the optimization study, from the mechanical point of view.





(updated detector response not included)

Presentations:
[1] L. D'Alessi *et al.* [ESSνSB], "Neutrino Beam Optimization for the ESSnSB Experiment", International Research Network - Neutrino 2021.

General conclusions and additional issues under investigation

- Proposed design appears feasible, but still more research (including experiments) is required
- Calculation of dynamic stress in the spheres (target), horn and beam window
- Thermal insulation
- Safety and radiation issues
- The steps in the design of the target station are being redone for the geometry optimized using the genetic algorithm
- Additional experiments are needed in order to investigate several aspects of the target station design
- Future plans : next steps will be to expand studies to muon test facility

Contribution (in alphabetical order)

- AGH University of Science and Technology

  Piotr Cupiał, Mateusz Kozioł, Łukasz Łacny, Jacek Snamina

- Centre National de la Recherche Scientifique (FR)

  Eric Baussan, Elian Bouquerel, Loris D'Alessi, Marcos Dracos, Pascal Poussot, Julie Thomas, Jacques Wurtz, Valeria Zeter

- CERN

  Ilias Efthymiopoulos

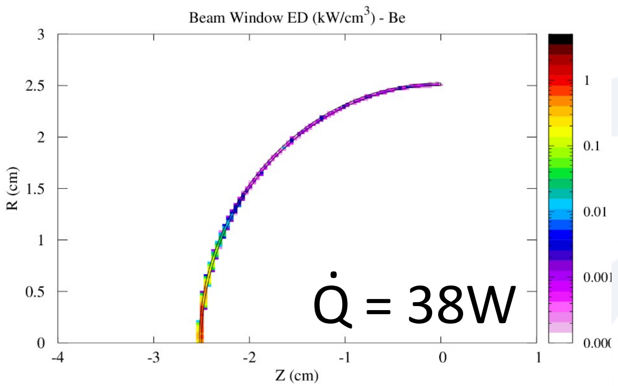
- Universität Hamburg (UHH)

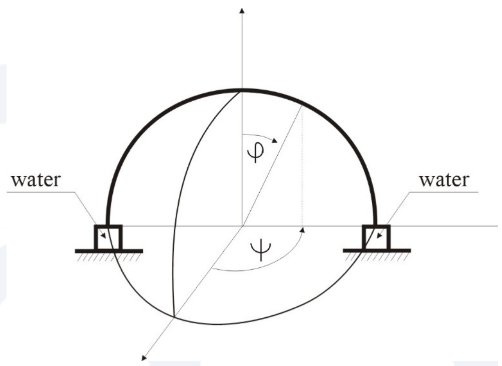
  Tamer Tolba

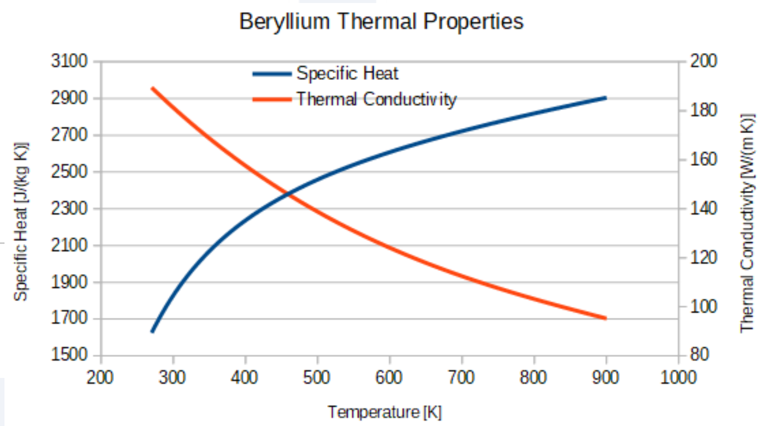
Target cooling table

		Titanium				Graphite			
MATERIAL PROPERTIES	Density [kg/m³]	4850				2250			
	Heat transfer coef. [J/kg K]	544.3				709			
	Thermal cond. [W/m K]	7.44				24			
ANALYSIS PARAMETERS AND RESULTS	Power distributed in target [kW]	138.6				78.6			
	Horn inner diameter [mm]	60		80		60			
	Shell hole cut-out type	same	prop	same	prop	same	prop	same	prop
	Max local temp [K]	844	577	881	600	516	458	412	377
	Max local velocity [m/s]	445	497	215	207	368	410	158	158
	Pressure drop [bar]	4.1	4.3	3.1	3.3	3.6	3.8	2.7	2.8

Beryllium beam window power deposition and cooling







- An analytical model has been developed, which allows for the calculation of the steady-state temperature in the beam window, under a train of beam pulses
- Steady-state results that account for an impulsive nature of the beam can differ from those calculated using power averaged over time, depending on the spatial distribution of deposited power
- It has been proposed that water cooling is by means of a channel at the beam window base
- Acceptable temperature levels are obtained under reasonable water flow conditions
- Additional analysis is still needed to determine the heat film coefficient more accurately, based on the water flow parameters