ESS
NEUTRINO
SUPER BEAM

and the ESSνSB+ project

NOW 2024 -09-04

J. Cederkall for the ESSnuSB collaboration

acknowledgment to T. Ekelöf (Uppsala) & M. Dracos (Strasbourg)

Funded by the Horizon 2020
Framework Programme of the
European Union

What is ESS and why ESSvSB?

What is ESS and why ESSvSB?

- ESS: the European Spallation Source

- European project for cold and ultracold neutron producution via spallation.

- An MW SC LINAC that is expected to be the highest power proton linac existing, is a key component, cmp e.g. with the previous SPL study at CERN (or the current SNS at ORNL).

Why:

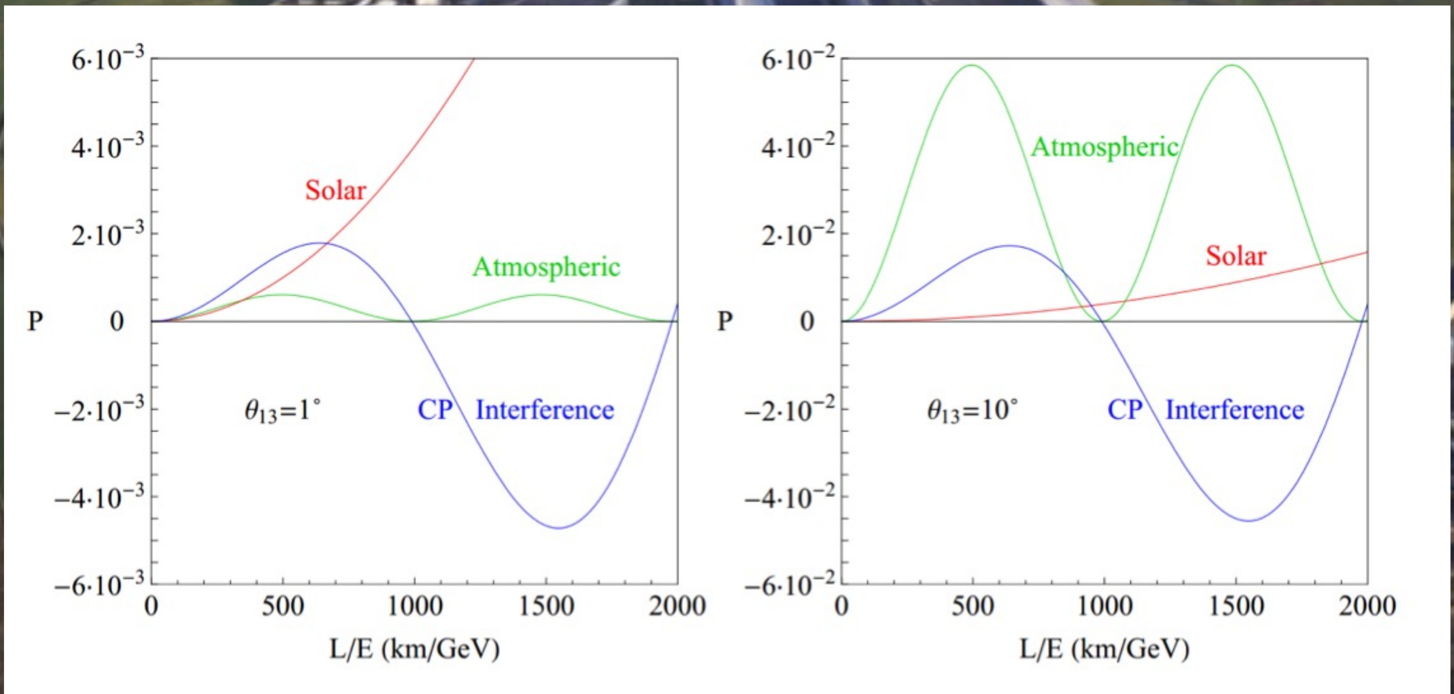
- Use investment in European accelerator infrastructure and exploit it for different types of physics if possible.

- Use the high power of ESS to produce an intense enough beam to reach the second oscillation maximum.

Physics motivation

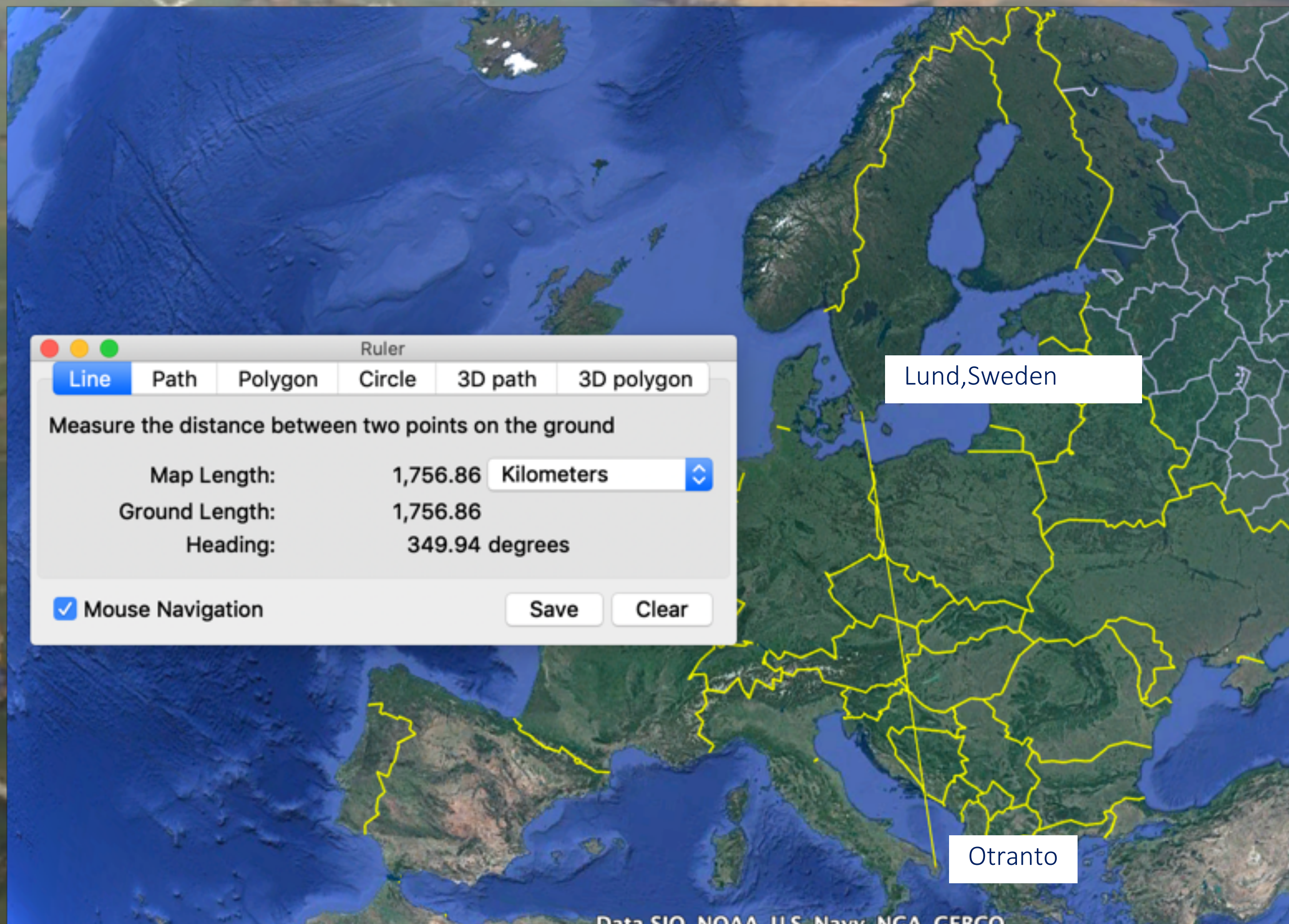
Measure δ_{CP} at second oscillation maximum

$$
\begin{aligned}
P^{\pm}(\nu_\mu \rightarrow \nu_e) \; &= \; s_{23}^2 \sin^2(2\theta_{13}) \sin^2(\Delta_{31}) && \text{(atmospheric)} \\
&+ \; c_{23}^2 \sin^2(2\theta_{12}) \sin^2(\Delta_{21}) && \text{(solar)} \\
&+ \; J' \cos(\mp\delta_{CP} - \Delta_{31}) && \text{(CP interference)}
\end{aligned}
$$



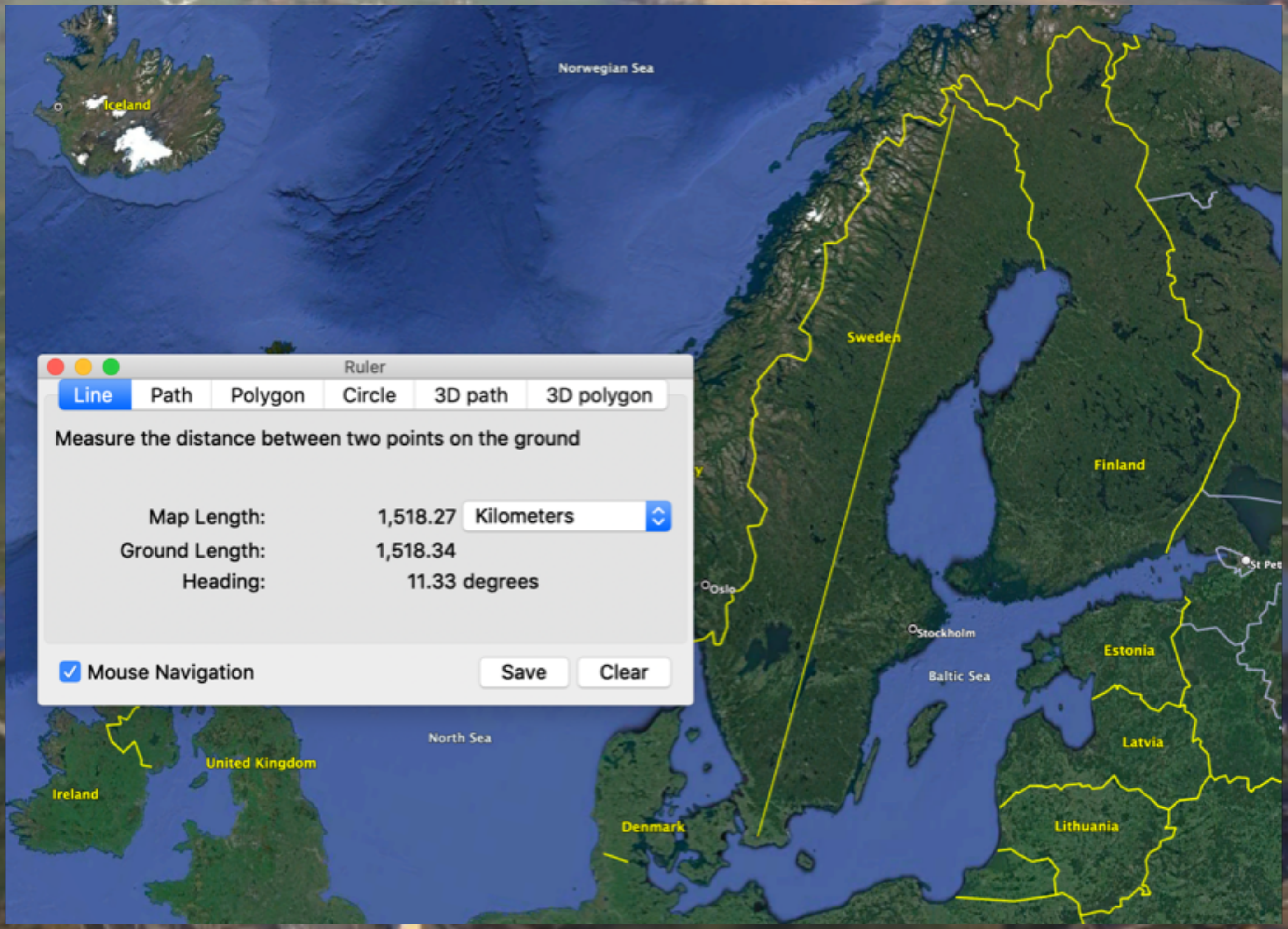
$\theta_{13} = (8.9 \pm 0.4)^\circ$

Where?

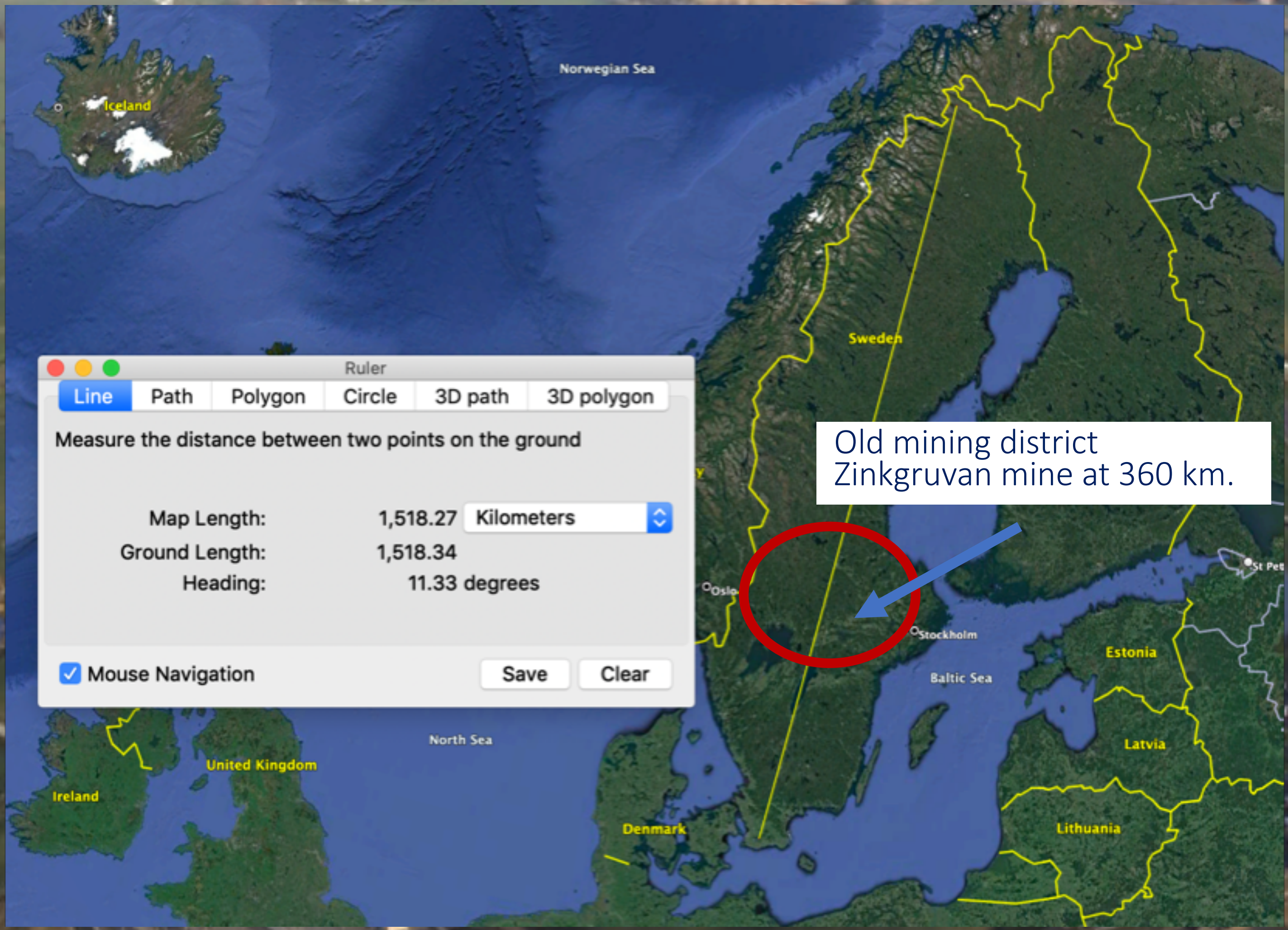


Ruler
Line
Path
Polygon
Circle
3D path
3D polygon
Measure the distance between two points on the ground
Map Length: 1,756.86 Kilometers
Ground Length: 1,756.86
Heading: 349.94 degrees
Mouse Navigation
Save
Clear
Lund,Sweden
Otranto
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

More geography…



More geography…



Old mining district
Zinkgruvan mine at 360 km.

ESS basics and status

- Proton linac designed for 2 GeV protons and 5 MW on target
- 4000 kg, 2.5 m diameter tungsten target wheel
- 6000 ton steel shielding

2024:

Cavities in the accelerator tunnel

Target wheel mounted

ESS ready for first beam in 2026…

physical sciences forum

MDPI

Proceeding Paper

ESS Linac Overall Status and Normal-Conducting Linac Commissioning †

Ryoichi Miyamoto *, Mamad Eshraqi, Yngve Levinsen, Natalia Milas and Daniel Noll

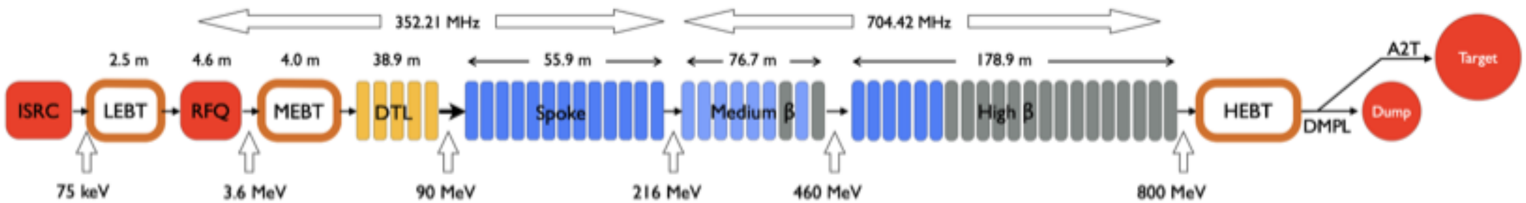


Figure 1. ESS linac schematic layout during the initial 2 MW Ops. The segments in the DTL and SC sections denote DTL tanks or cryomodules. The cryomodules in gray will not be powered during the initial Ops, making the beam energy and power 800 MeV and 2 MW for each.

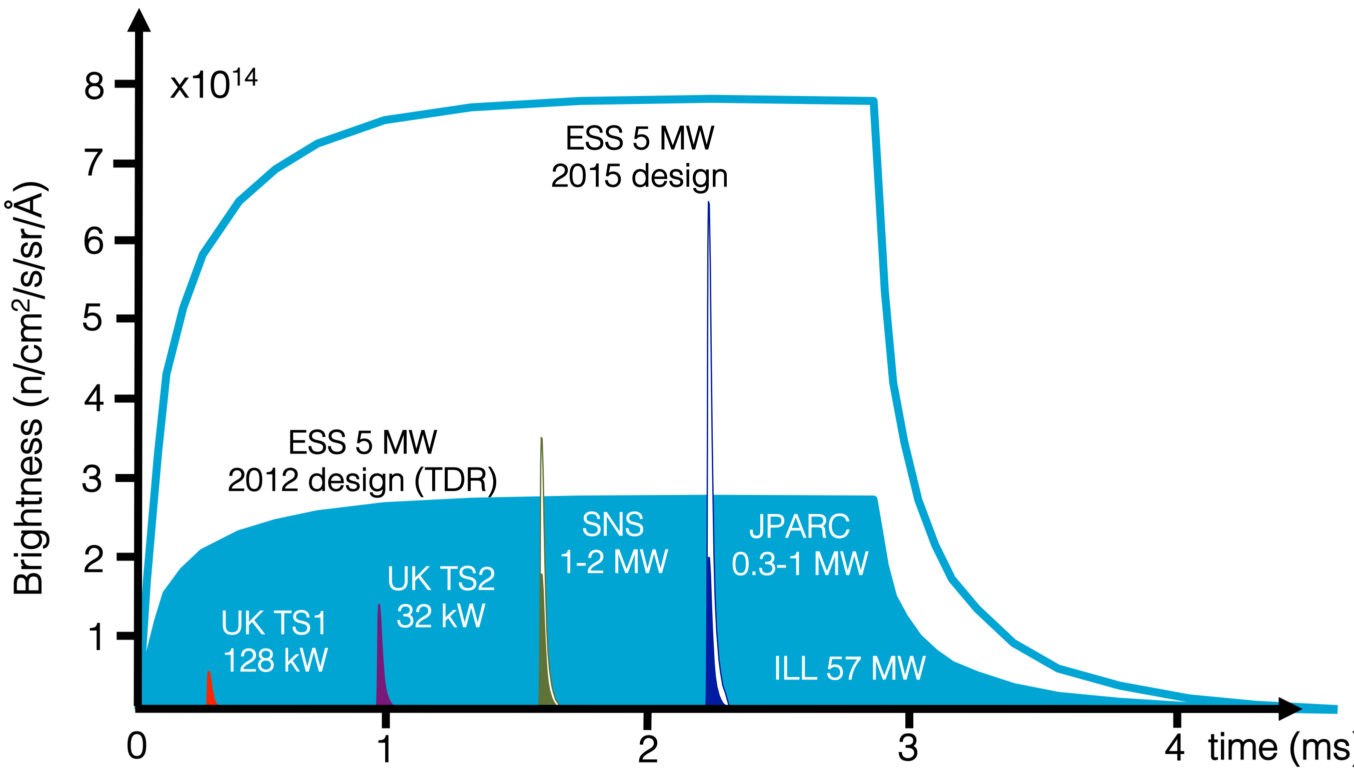
Table 1. ESS linac high-level beam parameters for the design and initial Ops.

Parameter	Unit	Design	Initial Ops
Power	MW	5	2
Kinetic energy	GeV	2	0.8
Peak current	mA	62.5	62.5
Pulse length	ms	2.86	2.86
Repetition rate	Hz	14	14
Duty factor	%	4	4

Table 2. ESS linac commissioning steps.

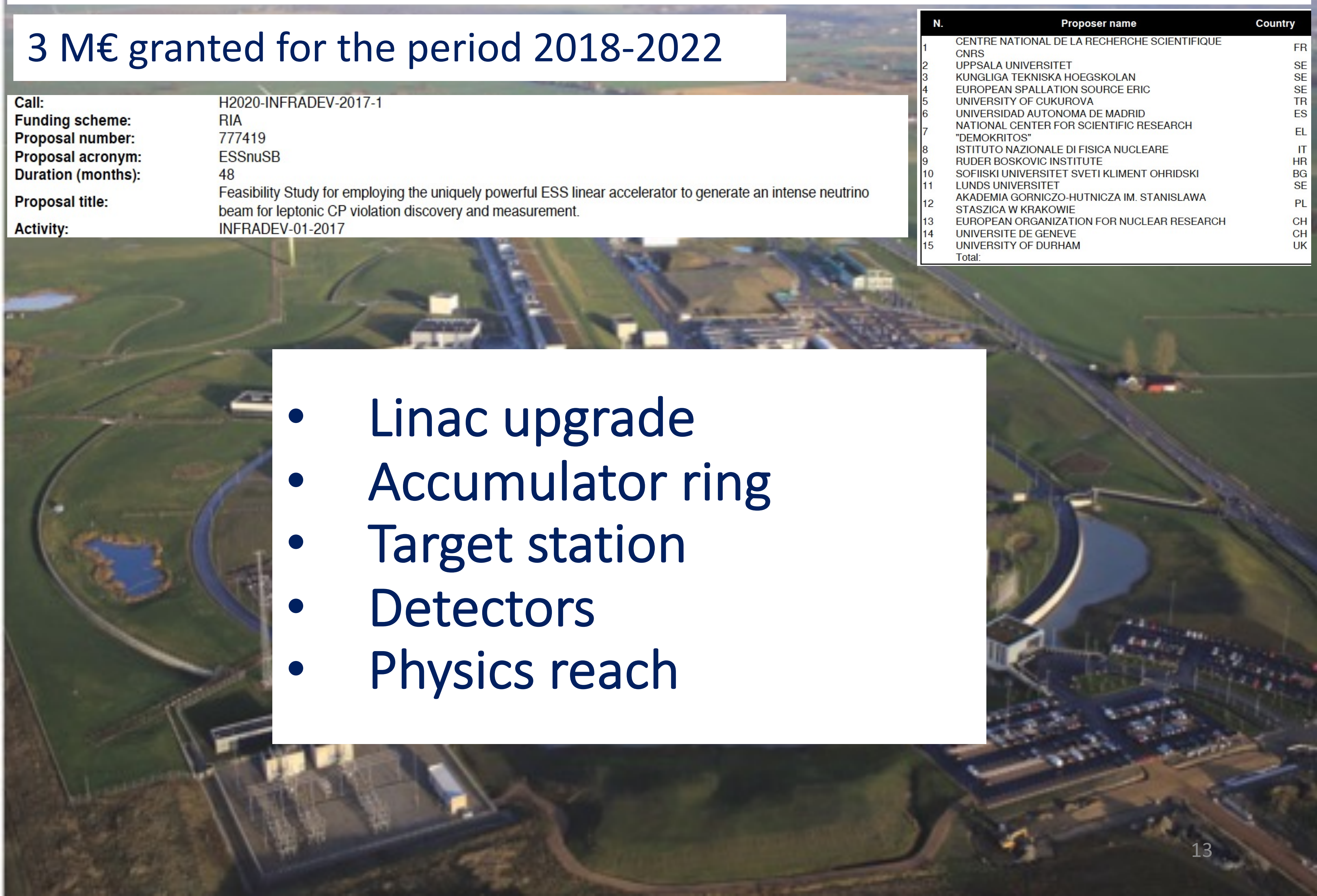
Step	Start	Energy [MeV]
Commissioning to LEBT	2018-09	0.075
Commissioning to MEBT	2021-11	3.62
Commissioning to DTL1	2022-05	21
Commissioning to DTL4	2023	74
Commissioning to Dump	2024	570
Commissioning to Target	2025	570
Start of user operations	2026	800

The pulse



x10^14
8
7
6
5
4
3
2
1
Brightness (n/cm²/s/sr/Å)
ESS 5 MW
2015 design
ESS 5 MW
2012 design (TDR)
SNS
1-2 MW
JPARC
0.3-1 MW
UK TS2
32 kW
UK TS1
128 kW
ILL 57 MW
0
1
2
3
4
time (ms)

First step: ESSnuSB Design Study January 2018 - March 2022



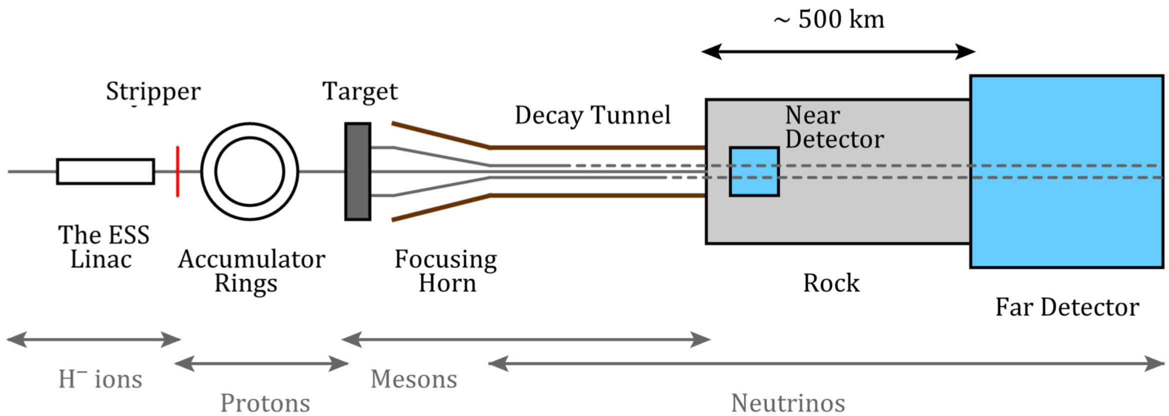
3 M€ granted for the period 2018-2022

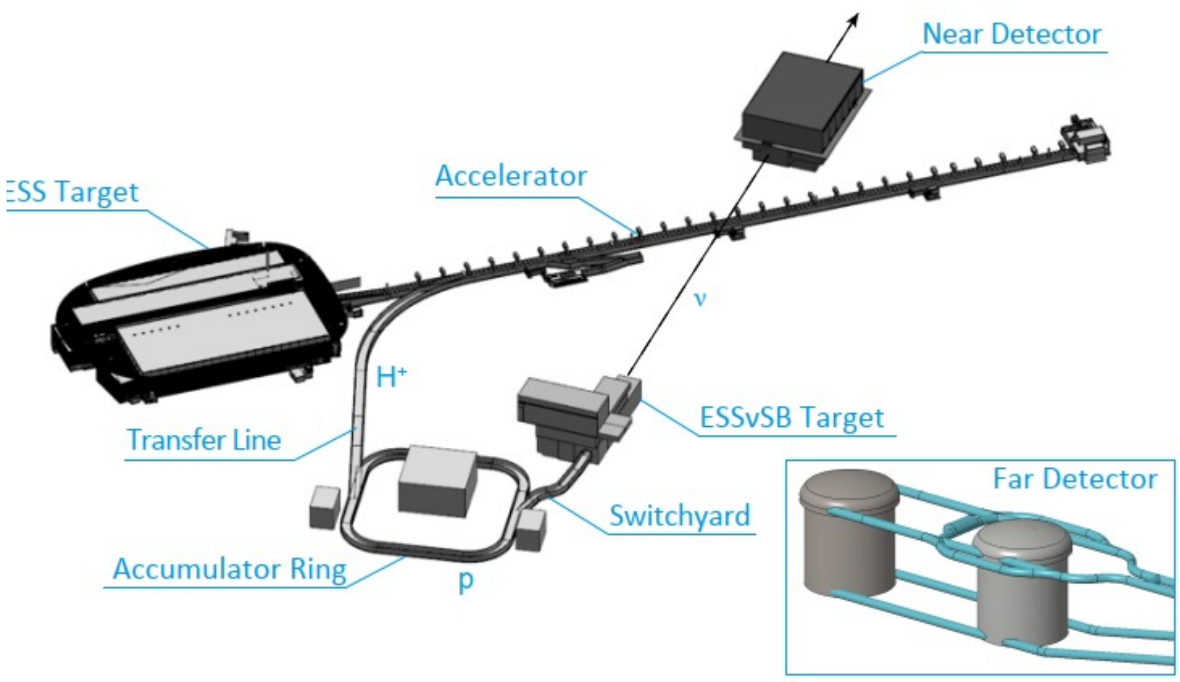
Call:	H2020-INFRADEV-2017-1
Funding scheme:	RIA
Proposal number:	777419
Proposal acronym:	ESSnuSB
Duration (months):	48
Proposal title:	Feasibility Study for employing the uniquely powerful ESS linear accelerator to generate an intense neutrino beam for leptonic CP violation discovery and measurement.
Activity:	INFRADEV-01-2017

N.	Proposer name	Country
1	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	FR
2	UPPSALA UNIVERSITET	SE
3	KUNGLIGA TEKNISKA HOEGSKOLAN	SE
4	EUROPEAN SPALLATION SOURCE ERIC	SE
5	UNIVERSITY OF CUKUROVA	TR
6	UNIVERSIDAD AUTONOMA DE MADRID	ES
7	NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS"	EL
8	ISTITUTO NAZIONALE DI FISICA NUCLEARE	IT
9	RUDER BOSKOVIC INSTITUTE	HR
10	SOFIISKI UNIVERSITET SVETI KLIMENT OHRIDSKI	BG
11	LUNDS UNIVERSITET	SE
12	AKADEMIA GORNICZO-HUTNICZA IM. STANISLAWA STASZICA W KRAKOWIE	PL
13	EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH	CH
14	UNIVERSITE DE GENEVE	CH
15	UNIVERSITY OF DURHAM	UK
	Total:	

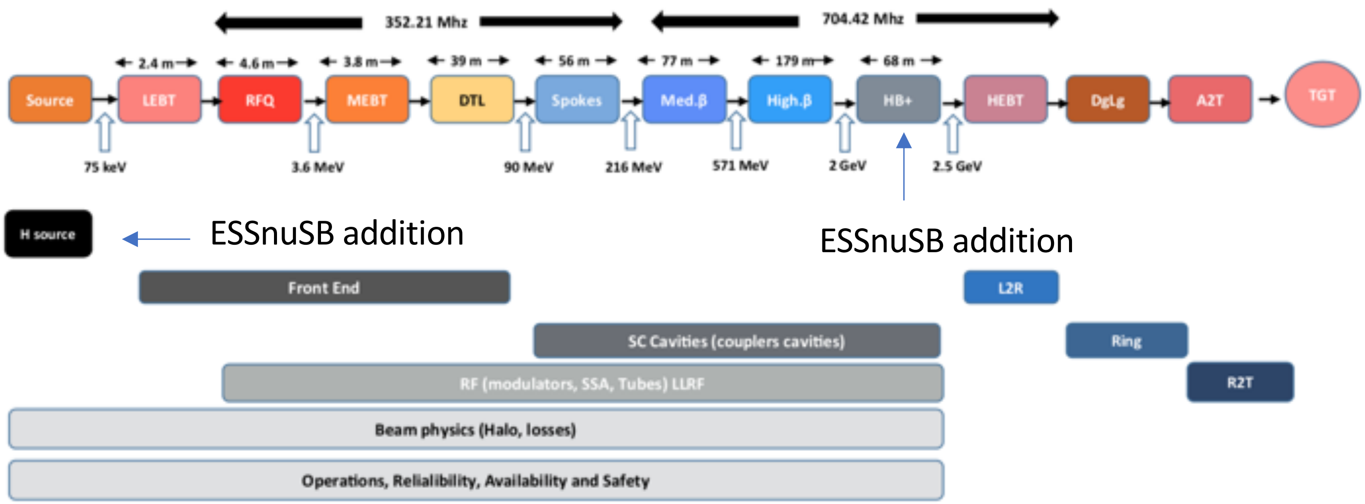
- Linac upgrade
- Accumulator ring
- Target station
- Detectors
- Physics reach

ESSnuSB layout

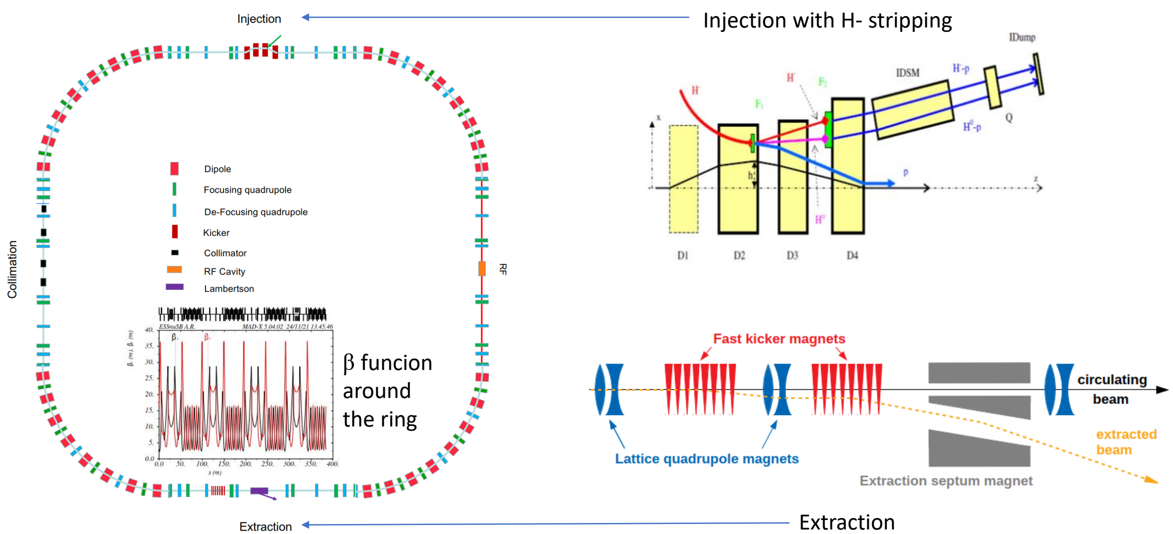




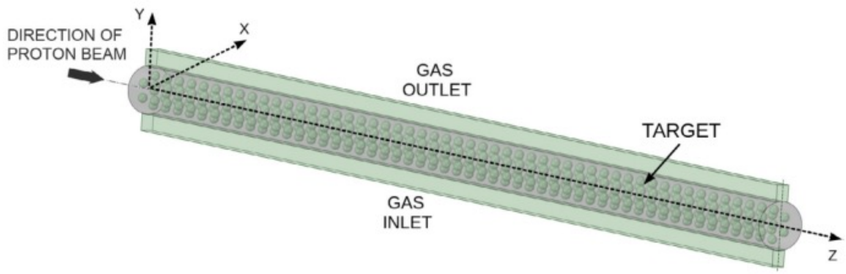
ESSnuSB accelerator upgrade

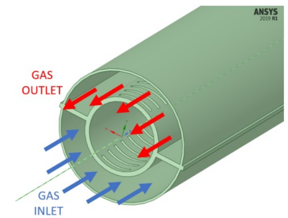


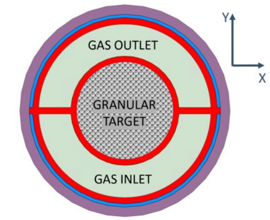
Compresses and divides the 2.86 ms long linac pulse to four 1.2 μs long pulses

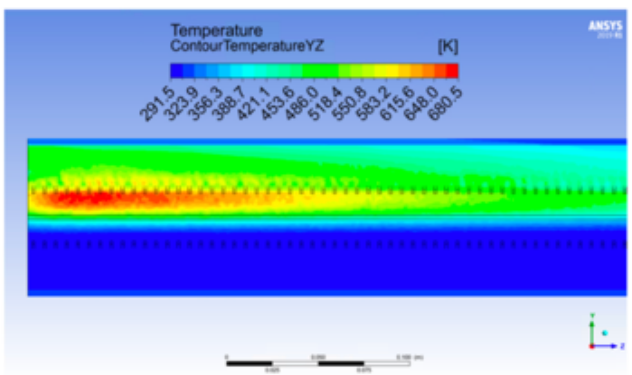


Target study, titanium spheres, cooling etc

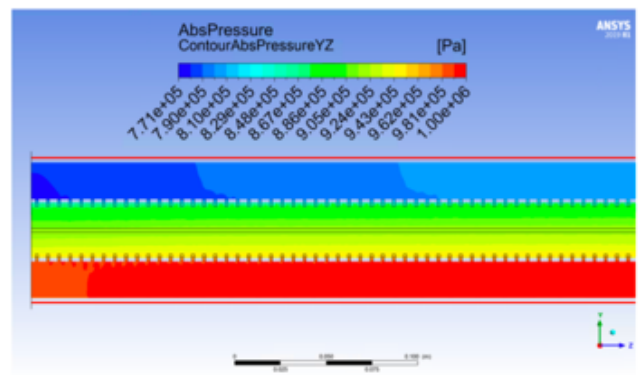




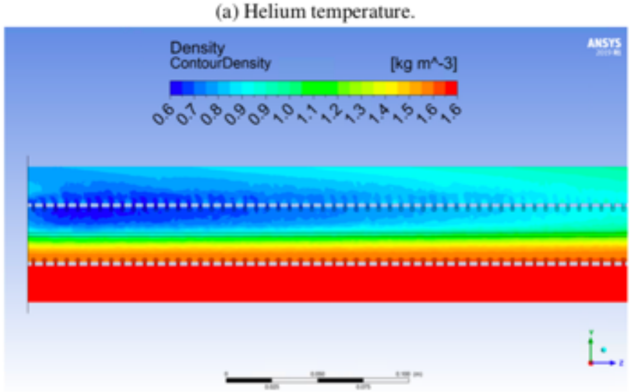




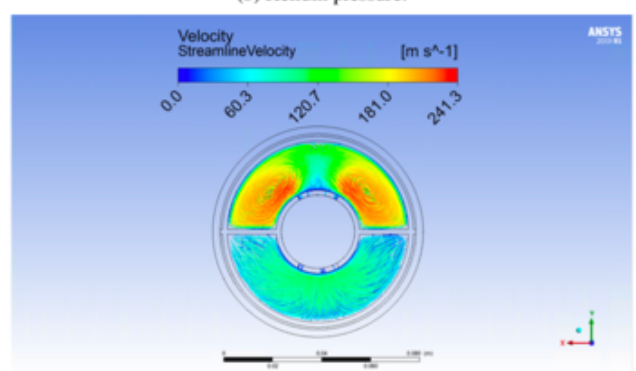
(a) Helium temperature.



(b) Helium pressure.



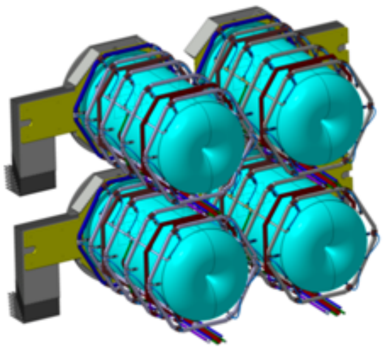
(c) Helium density.



(d) Helium velocity streamlines.

Magentic horn design…

Mechanical stress…



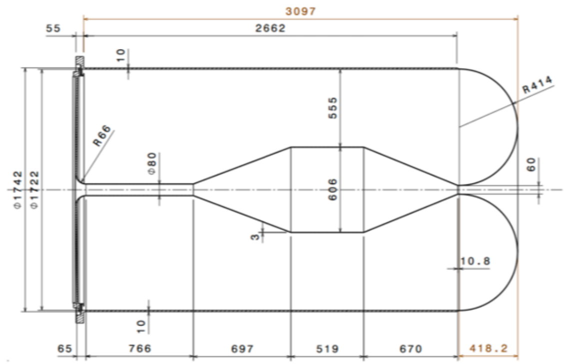
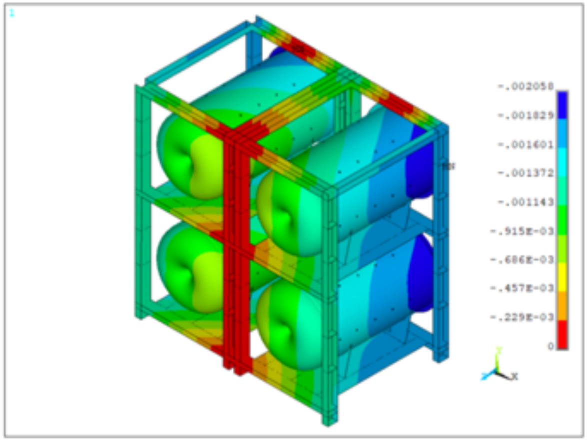
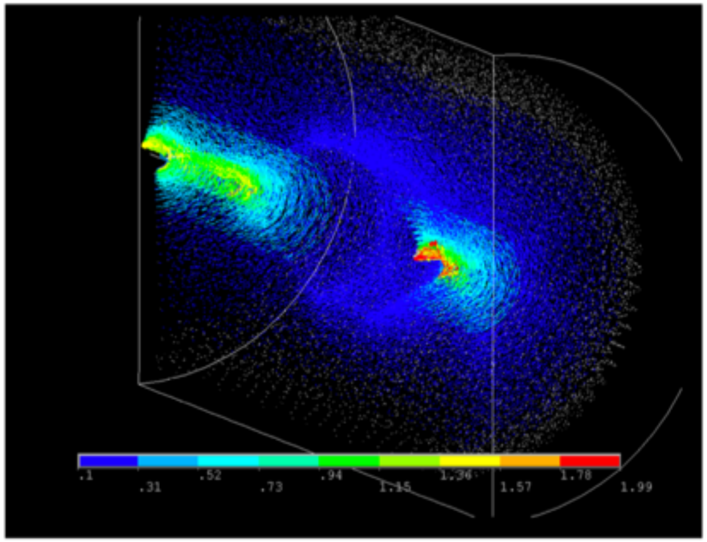


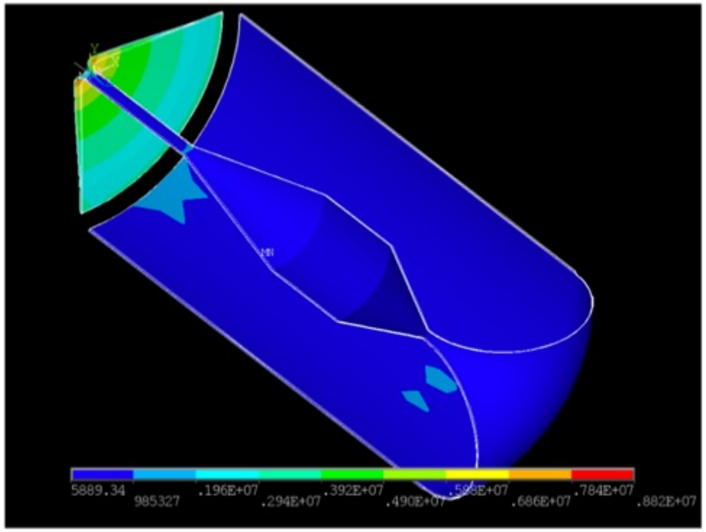
Figure 6.12: Sketch of the magnetic horn proposed for ESSνSB.



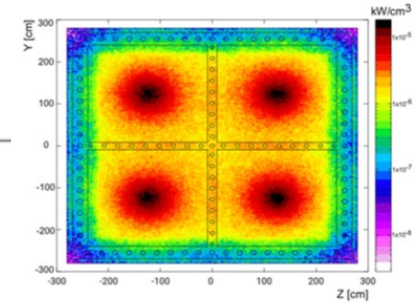
Magnetic field…



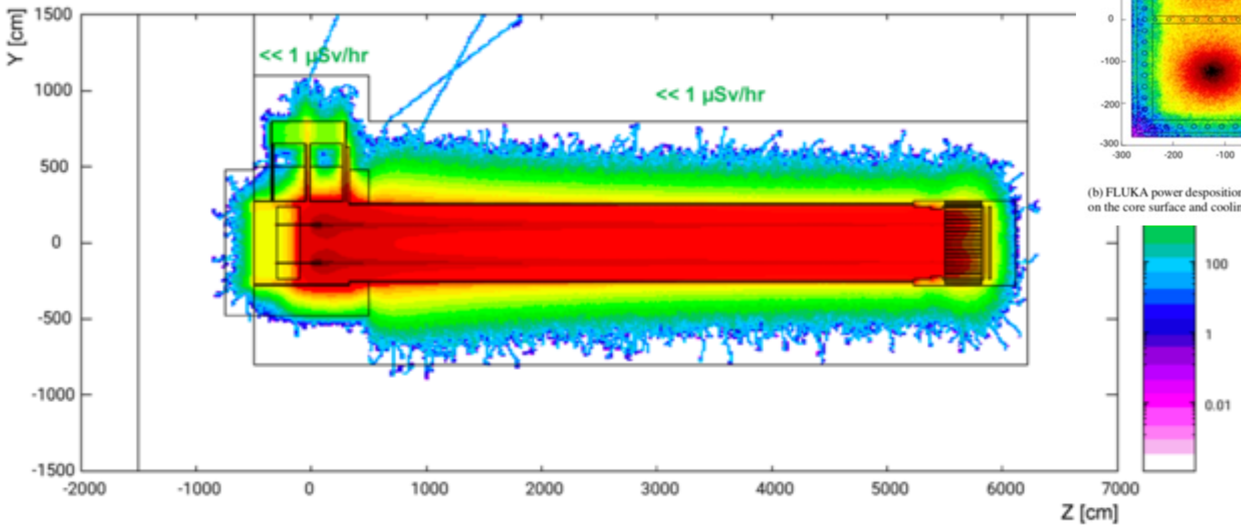
Thermal stress…

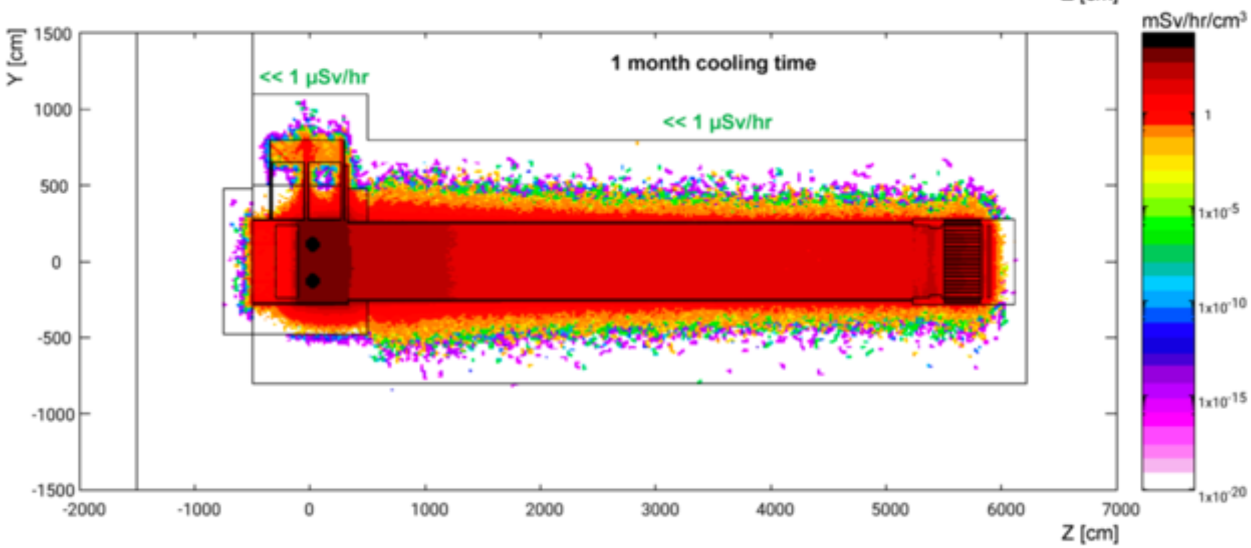


Decay tunnel, power deposition - activation

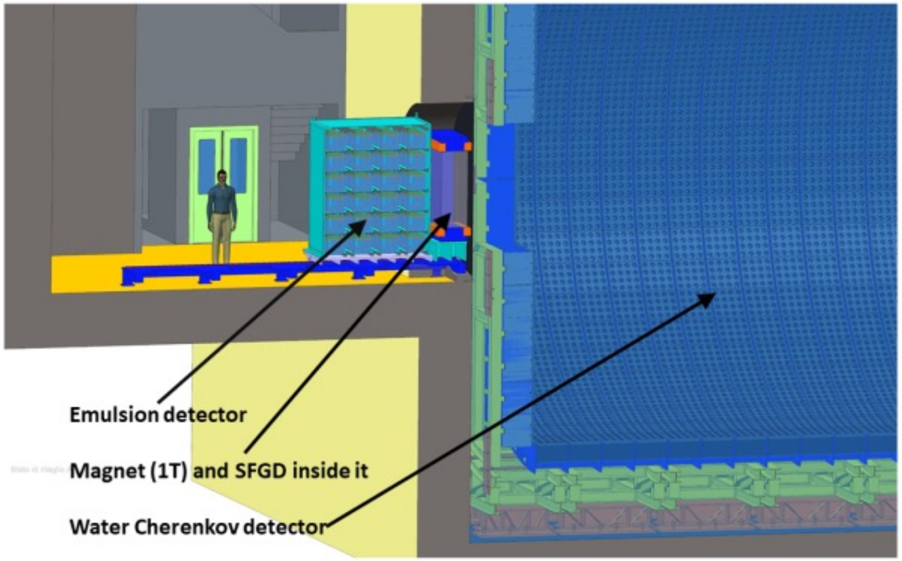


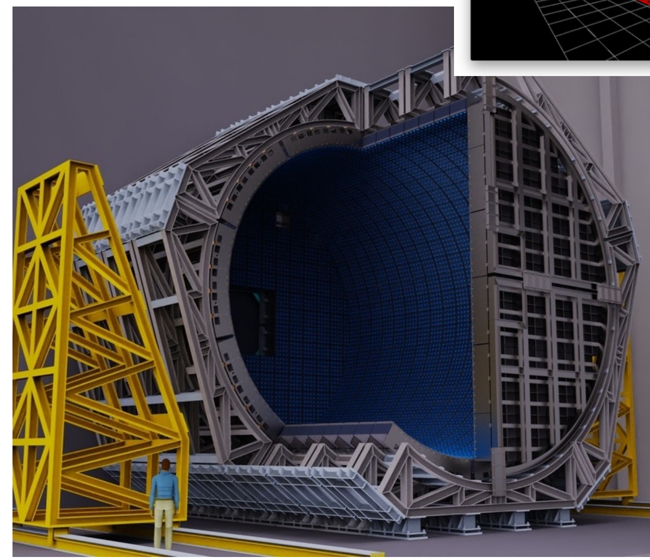
(b) FLUKA power desposition surface density distribution from the 4-horns, on the core surface and cooling heat sink plates.

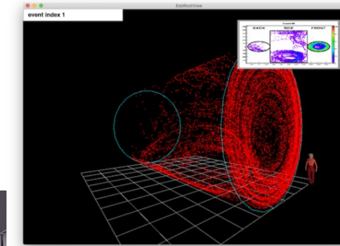




Near detector







Near Detector underground station

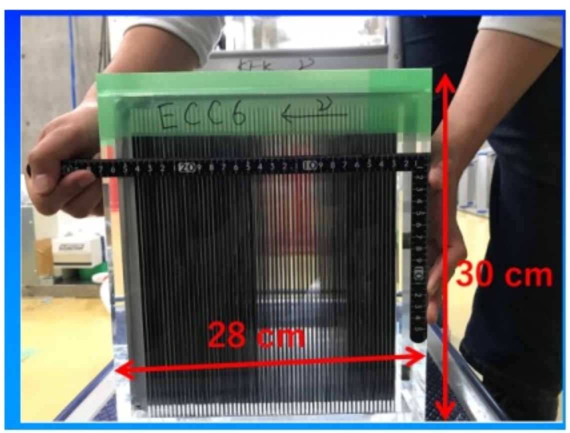
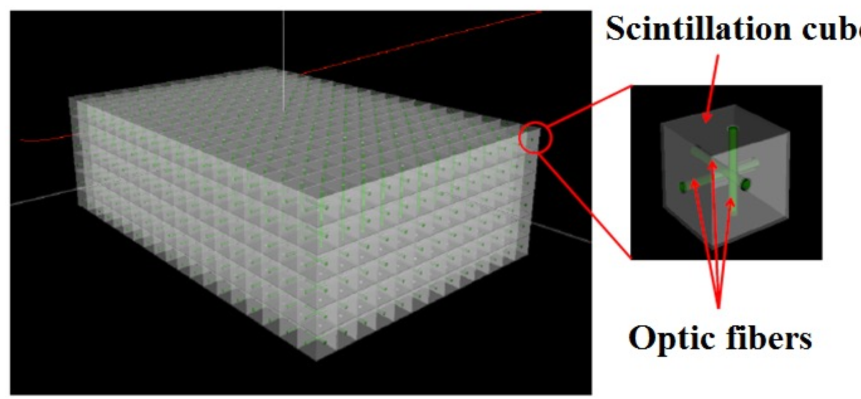


Figure 6.42: A photograph of the NINJA ECC element using water as target.



The super Fine-Grained Detector sFDG

Far detector, 2x270 kton Water Cherenkov

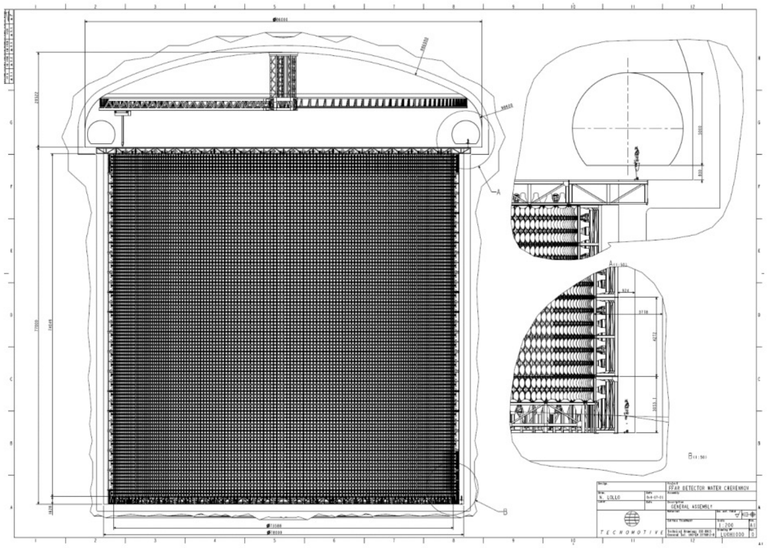
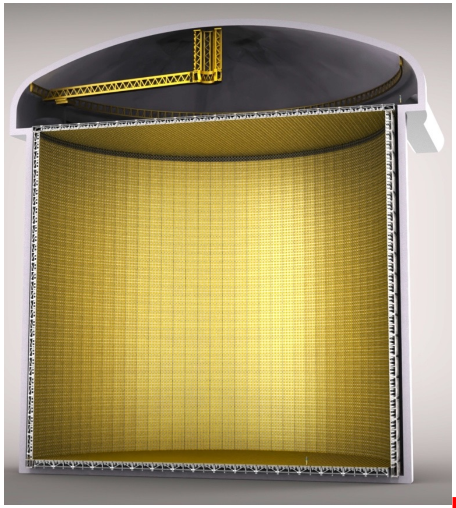
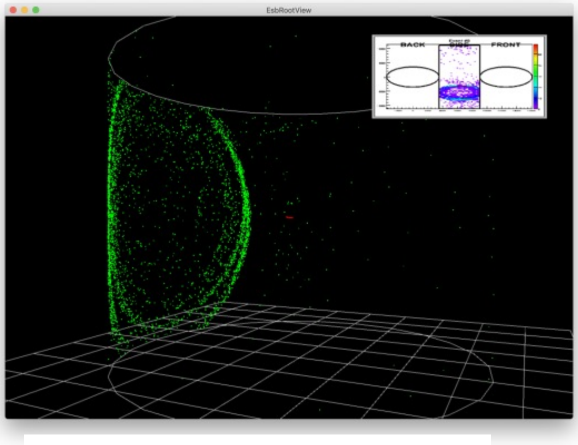


Figure 6.48: Overall view of a single far-detector tank with indicated dimensions.





Migration matrices

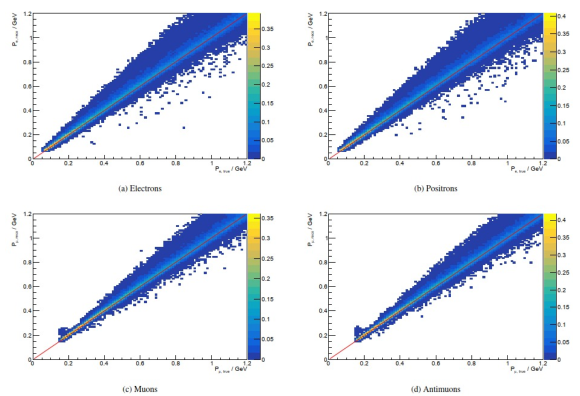


Figure 6.58: Distribution of reconstructed momentum as a function of true momentum for different flavours of charged leptons. These plots were produced using the charged lepton production.

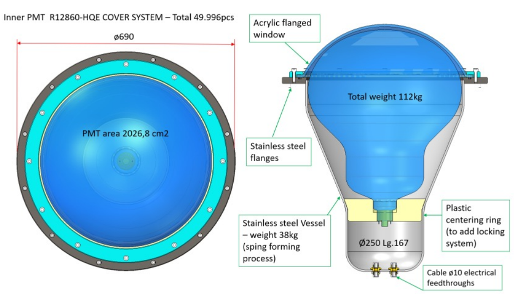
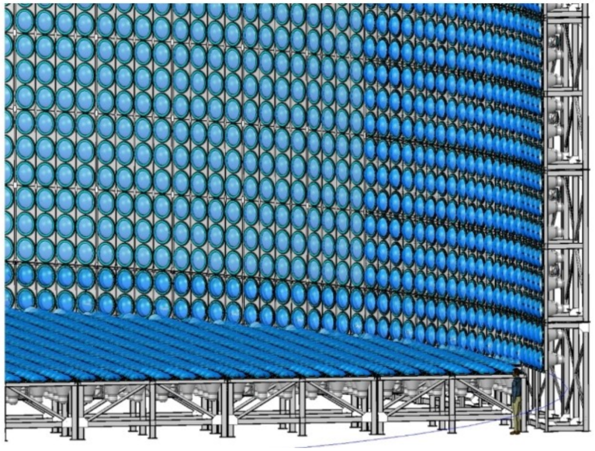
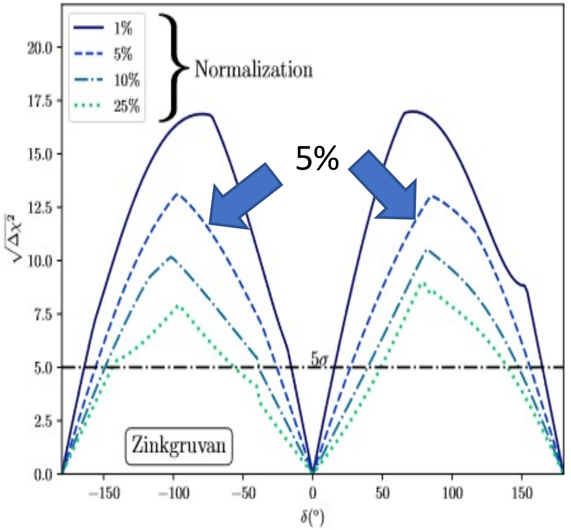


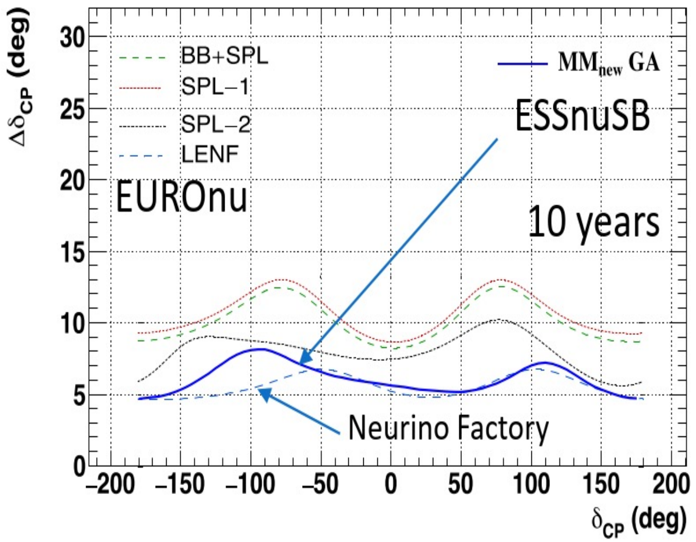
Figure 6.50: A schematic view of an inward-facing 20 inch PMT embedded in a protective cover.



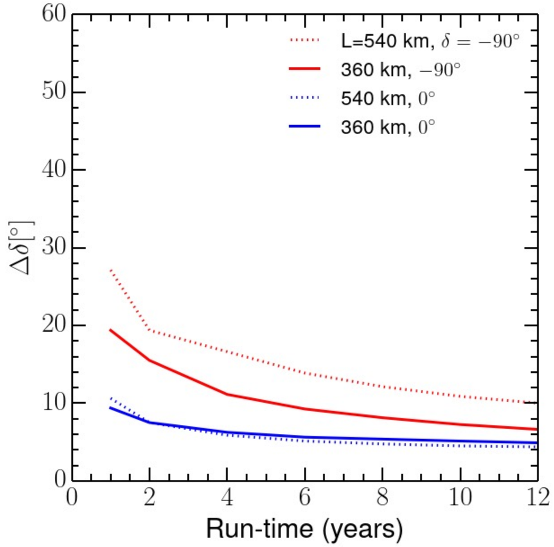
Performance for CPV discovery and δ_{CP} measurement



Discovery potential vs δ_{CP} angle after 10 years with 5% normalization error providing 70% coverage of all δ_{CP} vaues

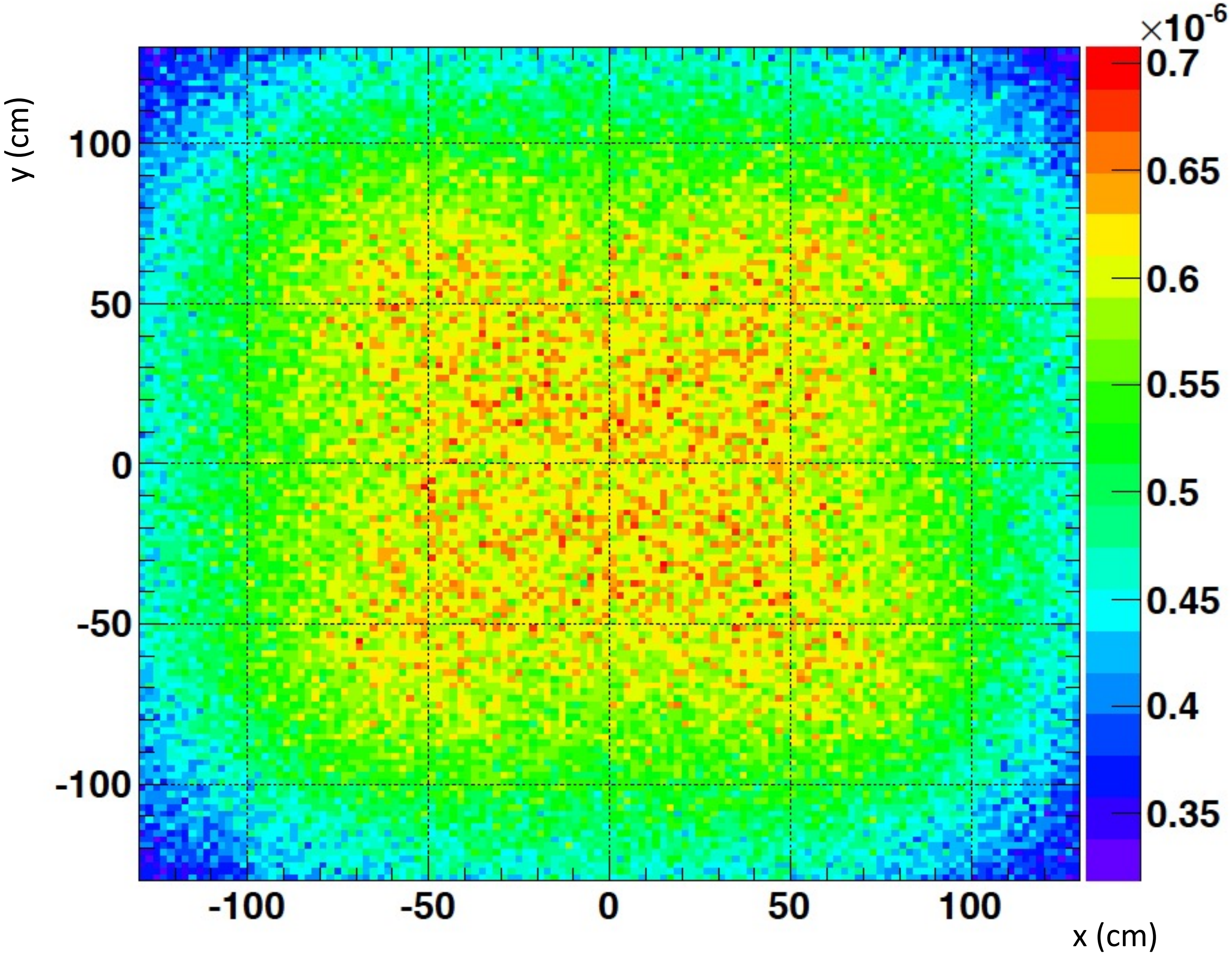


Error in δ_{CP} angle vs δ_{CP} angle after 10 years with 5% normalization error



Error in δ_{CP} angle vs run time with 5% normalization error

Muons at beam dump



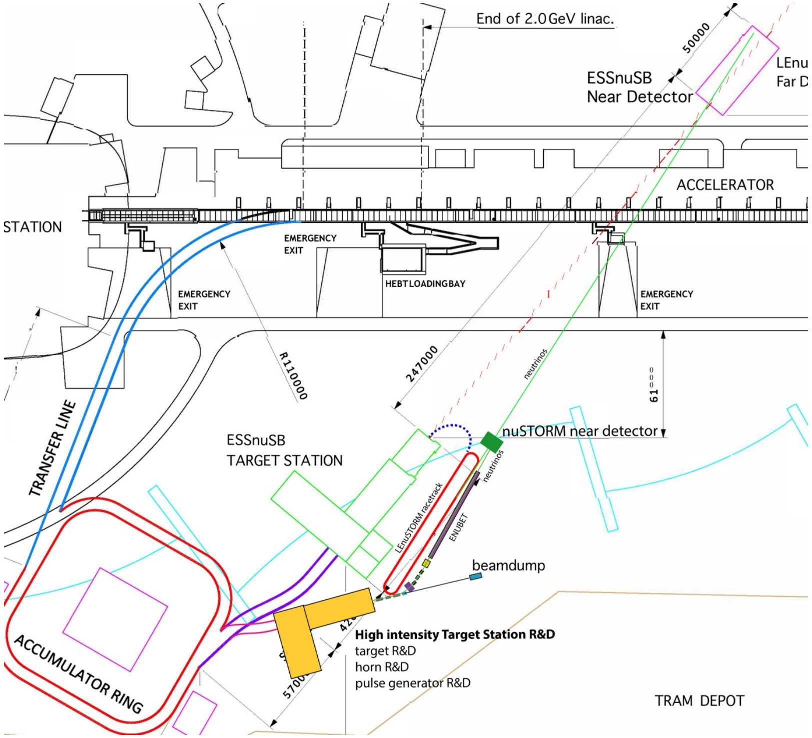
4.2×10^{20} μ/year

(16.3×10^{20} for 4 m^2)

- input beam for muon collider studies…

ESSνSB+, approved for 2023 - 2026, 3 M€

1. Collection of pions behind the target station to extract muons.
2. Design of a racetrack storage ring
3. Design a Monitored Neutrino Beam (low energy ENUBET)
4. Investigate Gd doping
5. Non-beam physics simulations
6. Optimize the performance of the ESSνSB accelerator complex



More effective software tools:

Change from likelihood-analysis to neural network to improve speed of identification. First results show an improvement of a factor ~ 10^3 in reconstruction time. We aim to use this to improve/investigate the design of the ND in more detail (for cost saving).

- ESSvSB+ has started.
- Several interesting and challenging tasks.
- Steady progress with report planned for 2026.

- Interested in contributing to the project?

- Contact Marcos Dracos, IPHC, Strasbourg or Tord Ekelof, Uppsala (or any other colleagues you know in the project)

Thank you!