ESS NEUTRINO SUPER BEAM

Funded by the Horizon 2020 Framework Programme of the European Union

The design and performance of the ESS neutrino Super Beam ESSνSB

Presentation at the KVA ESS Symposium in Lund 17 November 2022

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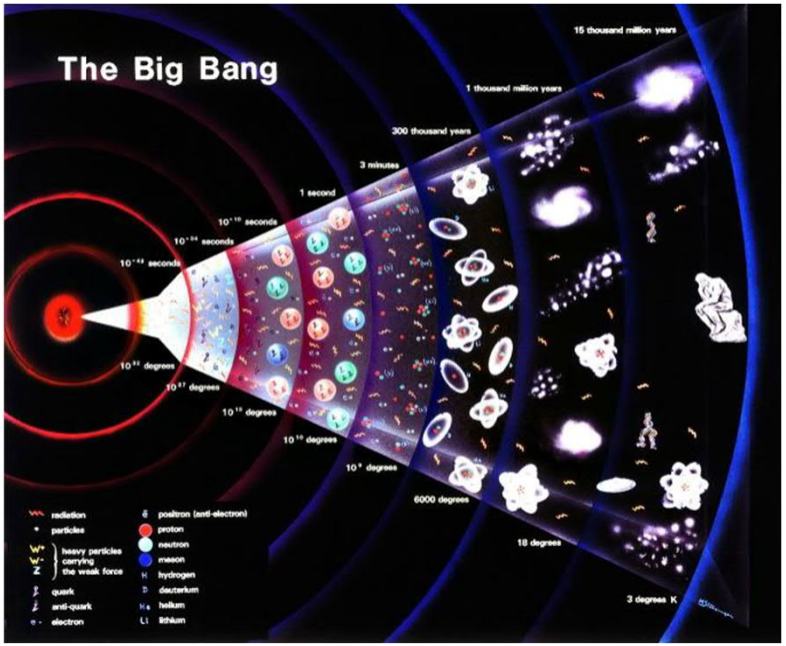
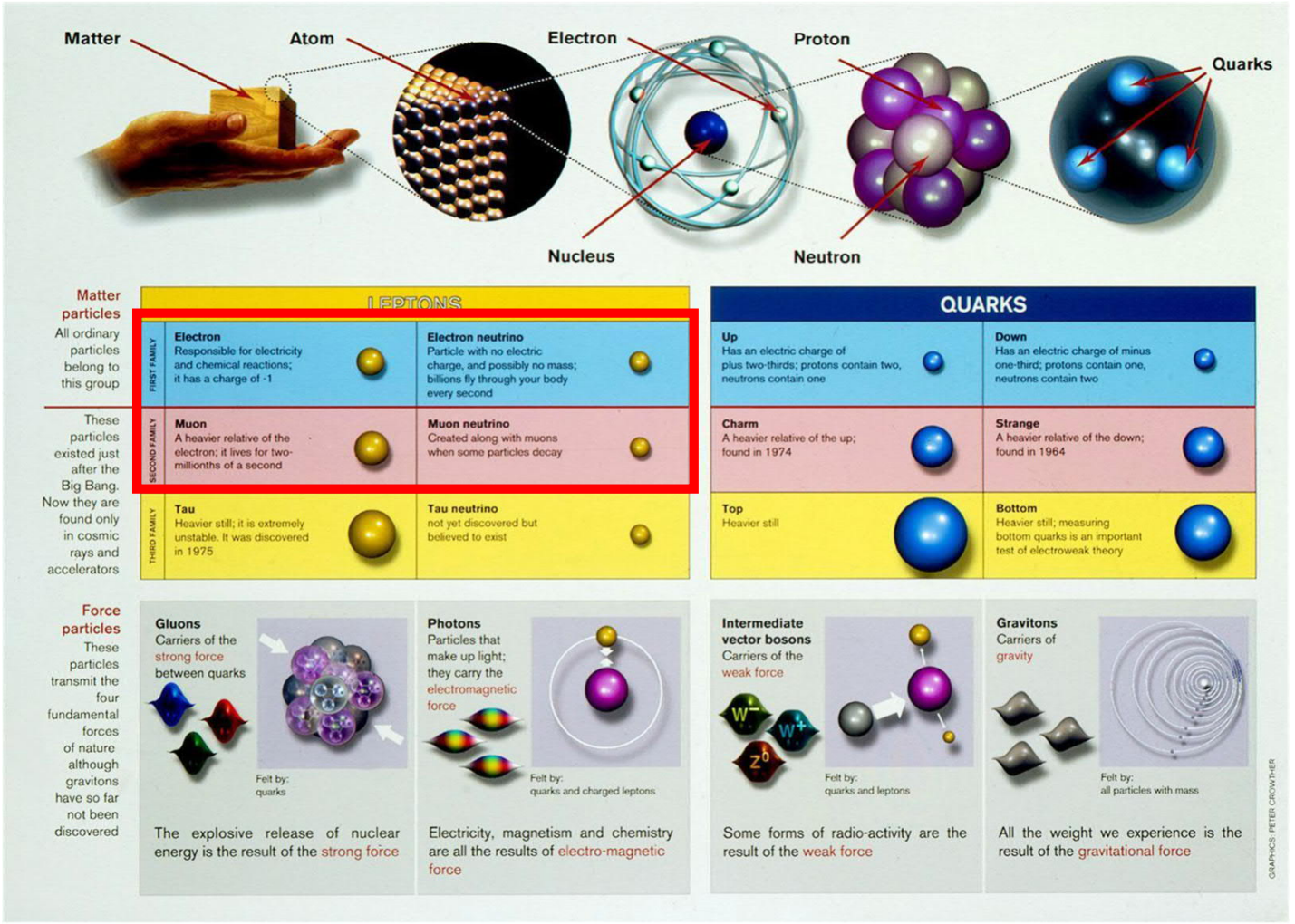
Why is there matter in the Universe?

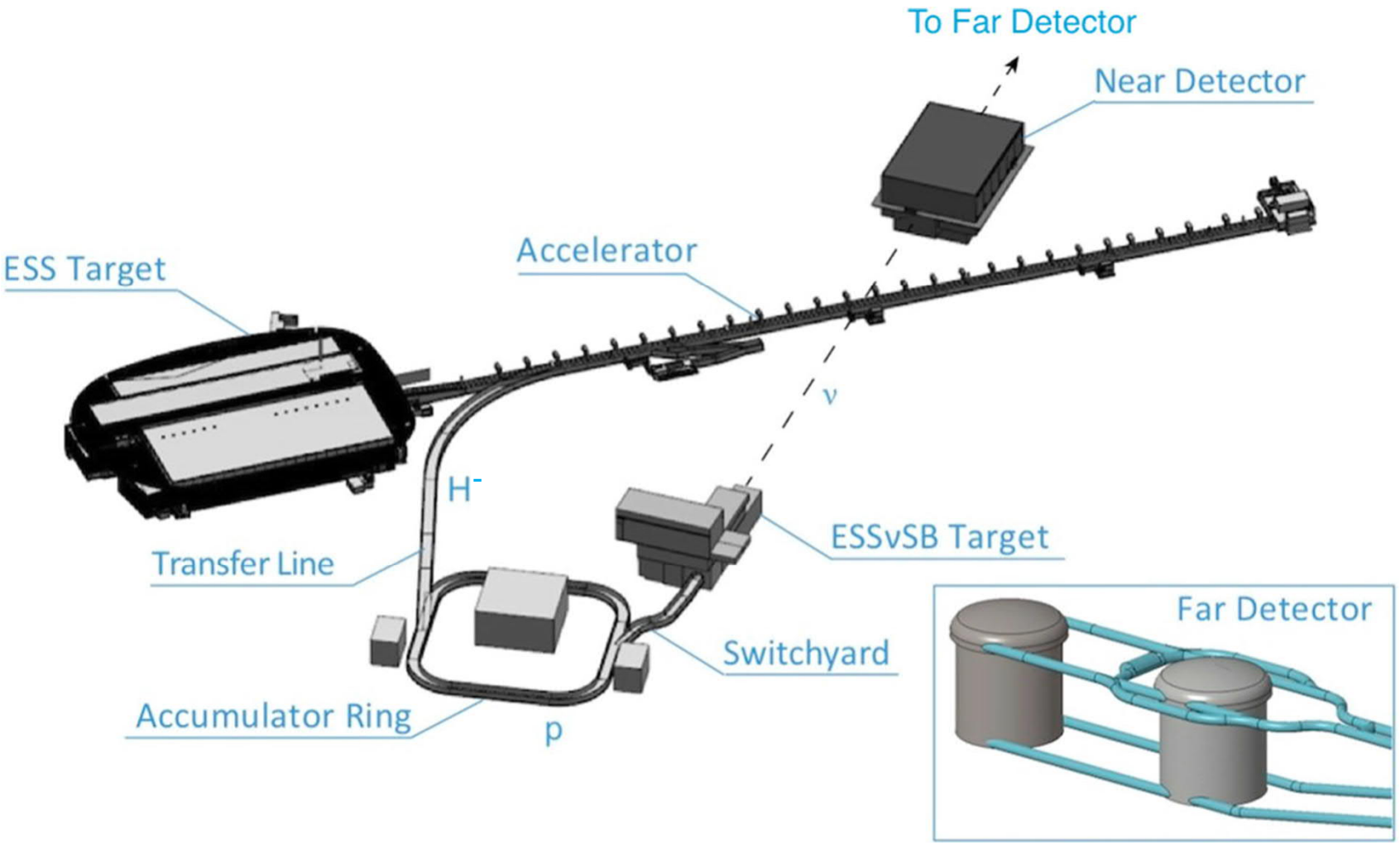


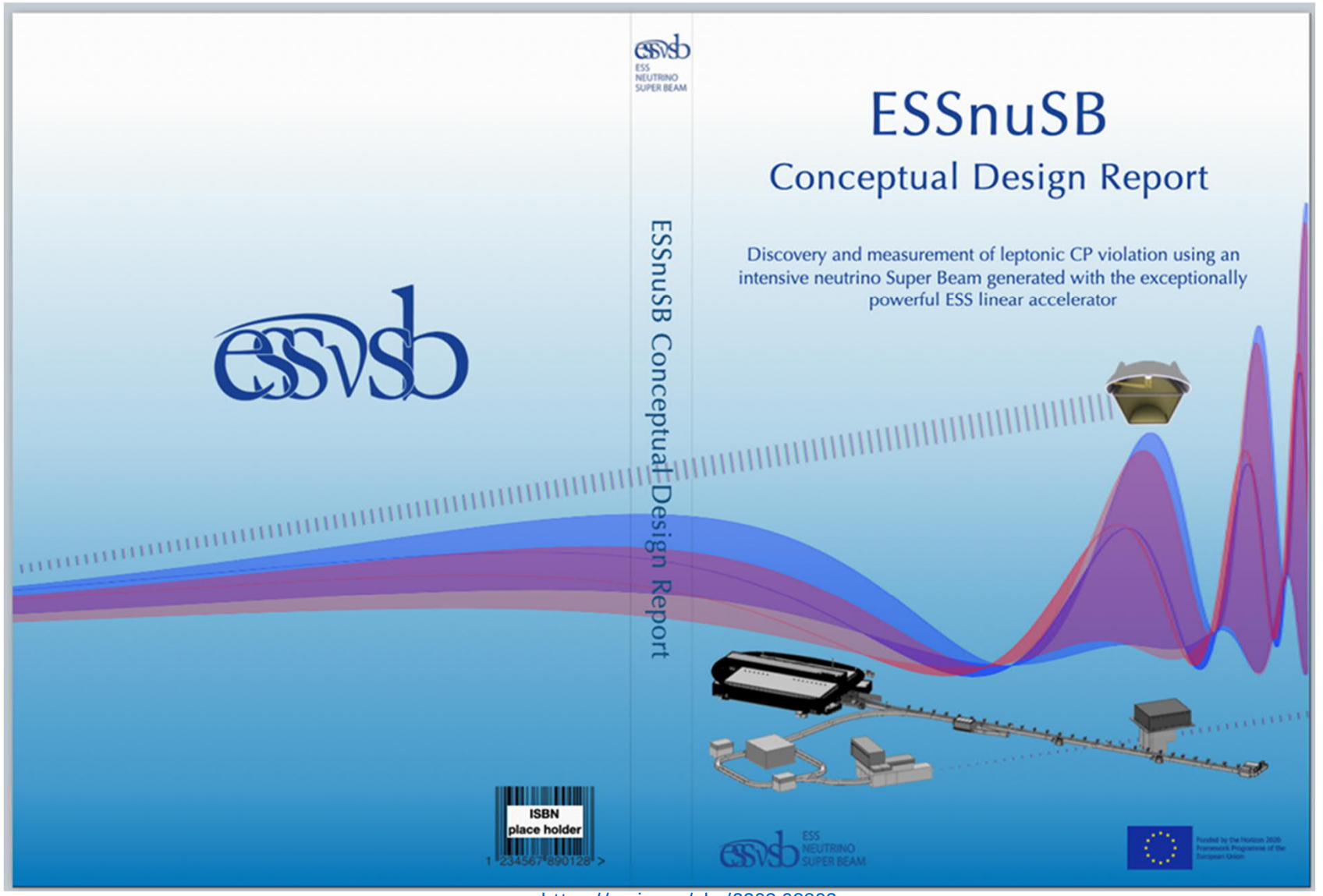
In the Big Bang equal amounts of matter and antimatter were created that instantly annihilated with each other again producing radiation.
Today we have a Universe consisting of matter and radiation but no antimatter.

How can we explain that?


Matter
Atom
Electron
Proton
Quarks
Nucleus
Neutron
Matter particles
All ordinary particles belong to this group
These particles existed just after the Big Bang. Now they are found only in cosmic rays and accelerators
LEPTONS
FIRST FAMILY
Electron
Responsible for electricity and chemical reactions; it has a charge of -1
Electron neutrino
Particle with no electric charge, and possibly no mass; billions fly through your body every second
SECOND FAMILY
Muon
A heavier relative of the electron; it lives for two-millionths of a second
Muon neutrino
Created along with muons when some particles decay
THIRD FAMILY
Tau
Heavier still; it is extremely unstable. It was discovered in 1975
Tau neutrino
not yet discovered but believed to exist
QUARKS
Up
Has an electric charge of plus two-thirds; protons contain two, neutrons contain one
Down
Has an electric charge of minus one-third; protons contain one, neutrons contain two
Charm
A heavier relative of the up; found in 1974
Strange
A heavier relative of the down; found in 1964
Top
Heavier still
Bottom
Heavier still; measuring bottom quarks is an important test of electroweak theory
Force particles
These particles transmit the four fundamental forces of nature although gravitons have so far not been discovered
Gluons
Carriers of the strong force between quarks
Felt by: quarks
The explosive release of nuclear energy is the result of the strong force
Photons
Particles that make up light; they carry the electromagnetic force
Felt by: quarks and charged leptons
Electricity, magnetism and chemistry are all the results of electro-magnetic force
Intermediate vector bosons
Carriers of the weak force
Felt by: quarks and leptons
Some forms of radio-activity are the result of the weak force
Gravitons
Carriers of gravity
Felt by: all particles with mass
All the weight we experience is the result of the gravitational force
GRAPHICS: PETER CROWTHER

The ESS neutrino Super Beam Project





https://arxiv.org/abs/2203.08803

ESSnuSB Design Study ESSνSB January 2018 - March 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:	

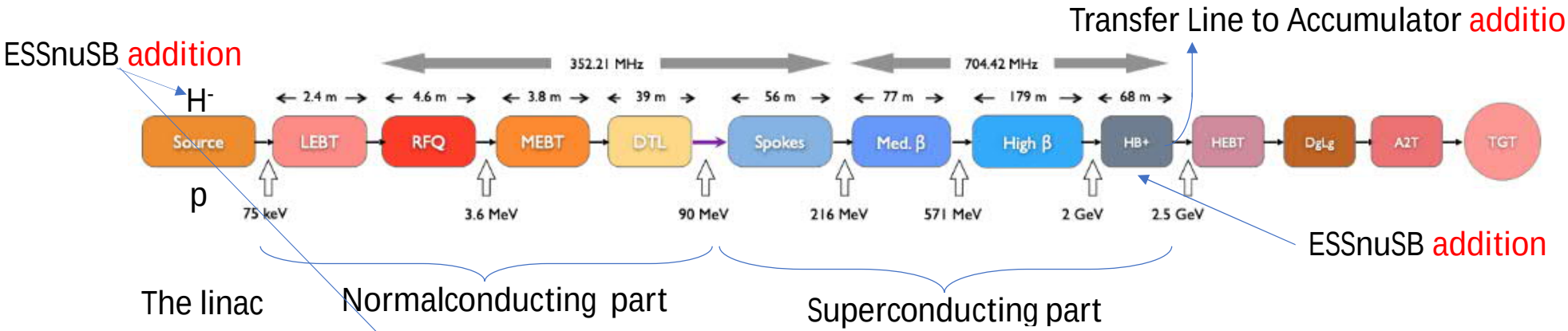
EU application submitted in 2017
3 M€ granted for the period 2018-2022

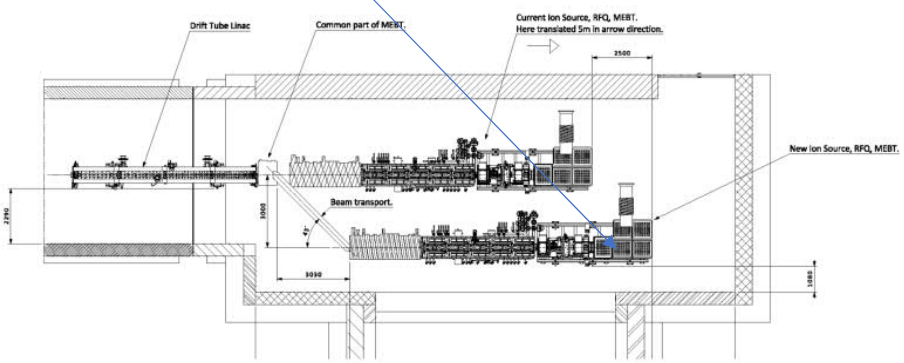
All results now published in
European Physics Journal Special Topics
220 pages
Publication date: 16 November 2022

https://link.springer.com/content/pdf/10.1140/epjs/s11734-022-00664-w.pdf

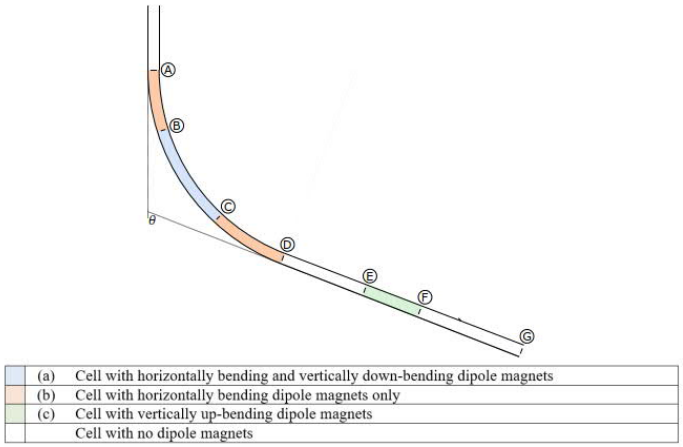
The ESS linac

2.86 ms pulses at 14 Hz pulse frequency increase to 28 Hz, implying an increase of the beam power from 5 MW to 10 MW



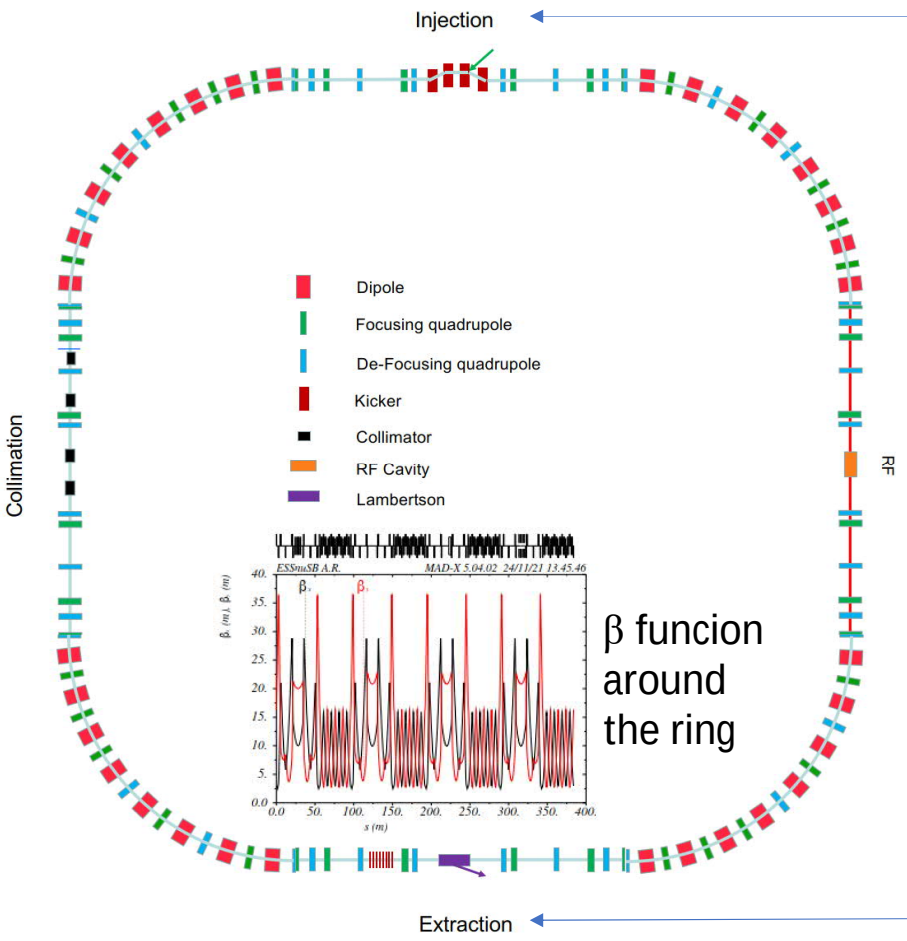


The merging of the H+ and the H- beams in the MEBT



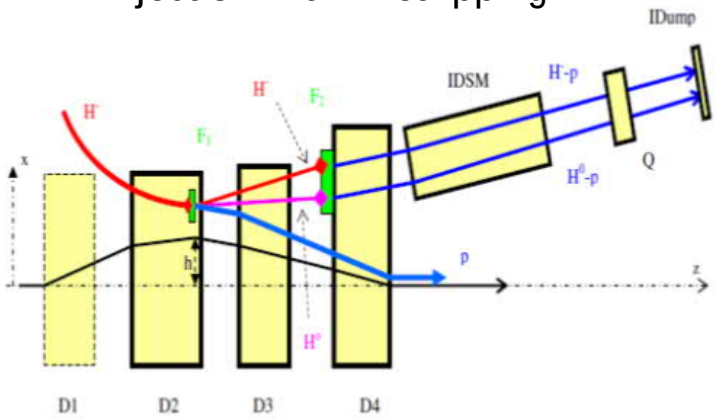
Transfer Line with bending limited by H^- Lorenz stripping

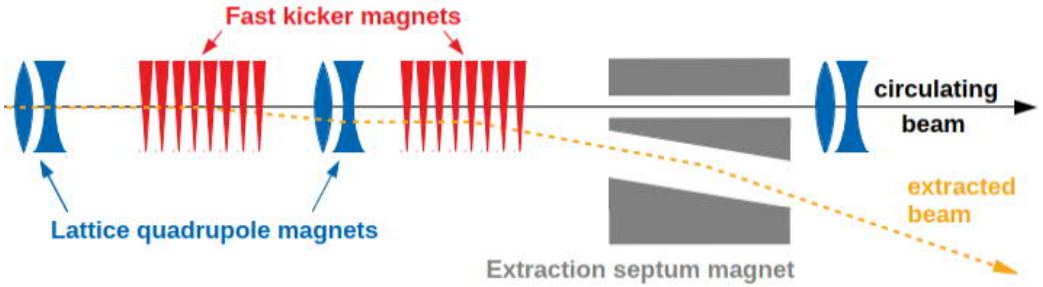
The Accmulator ring



β funcion around the ring

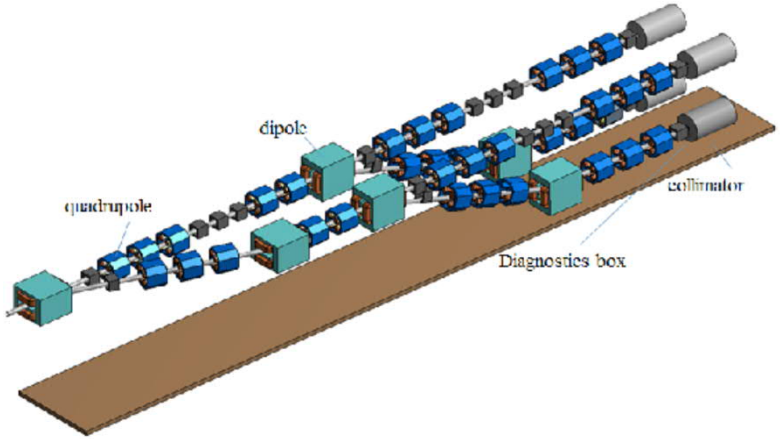
Injection with H- stripping

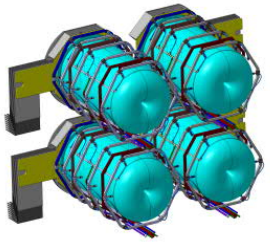




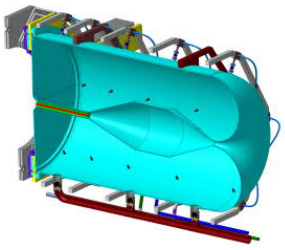
Extraction

Beam switch-yard and the target station

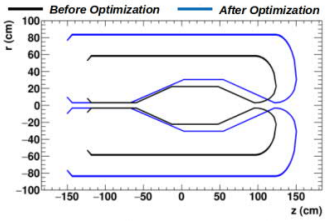




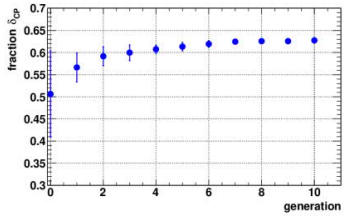
(a) The four-horn system.



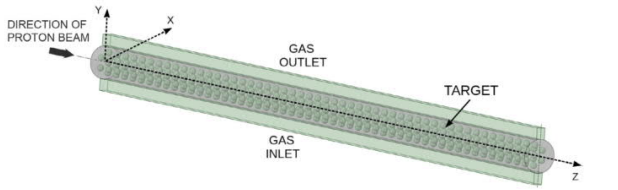
(b) Transverse view of one horn.

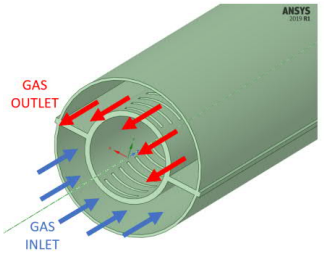


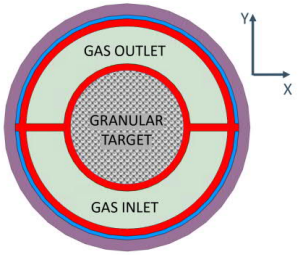
(a) Evolution of the horn profile.



(b) Genetic algorithm convergence throughout the iterative process.







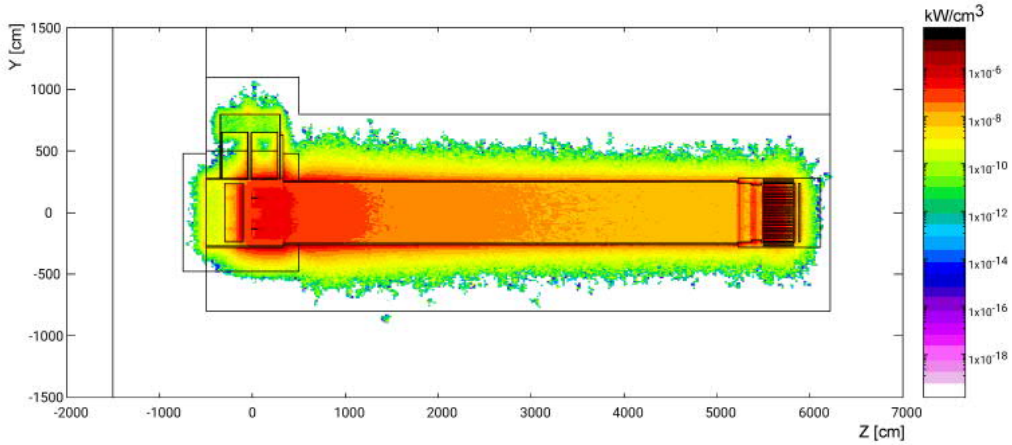
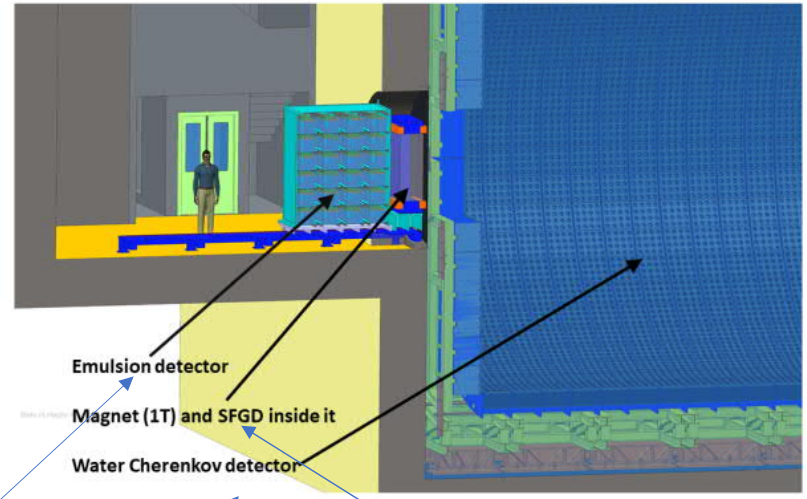
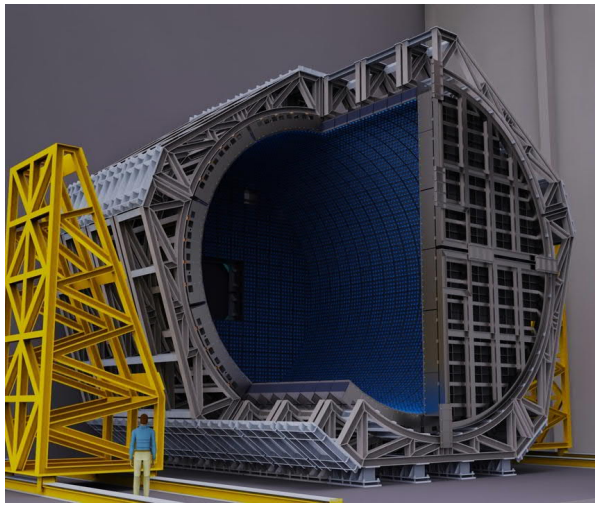


Figure 5.46: Energy deposition distribution in the target station facility.

The Near Detector



Near Detector underground station



A 1 kton water Cherenkov detector

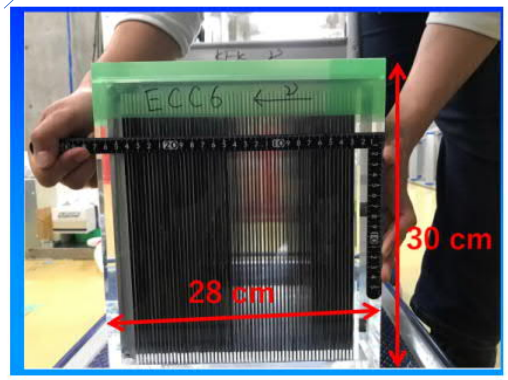
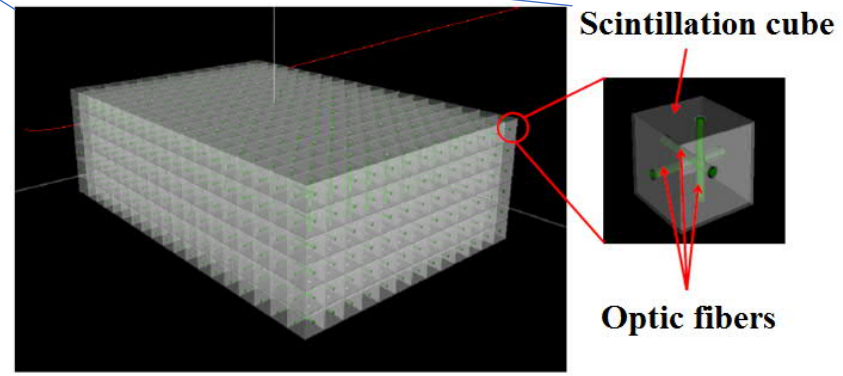
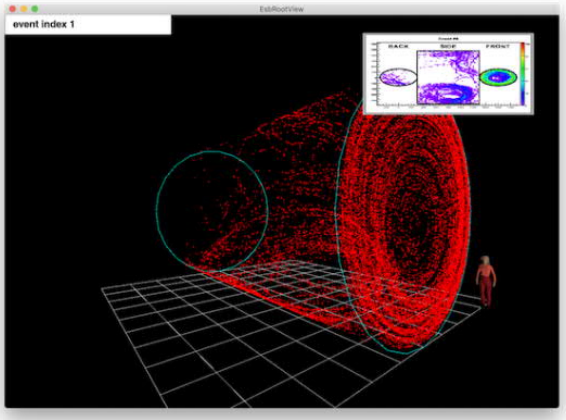


Figure 6.42: A photograph of the NINJA ECC element using water as target.

NINJA emulsion detector



The super Fine-Grained Detector sFDG



A muon Cherenkov ring

The Far Detector

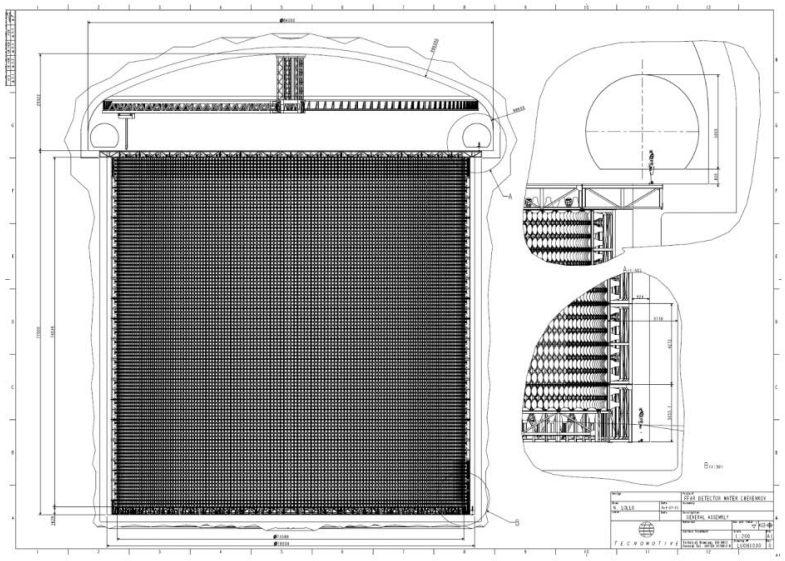
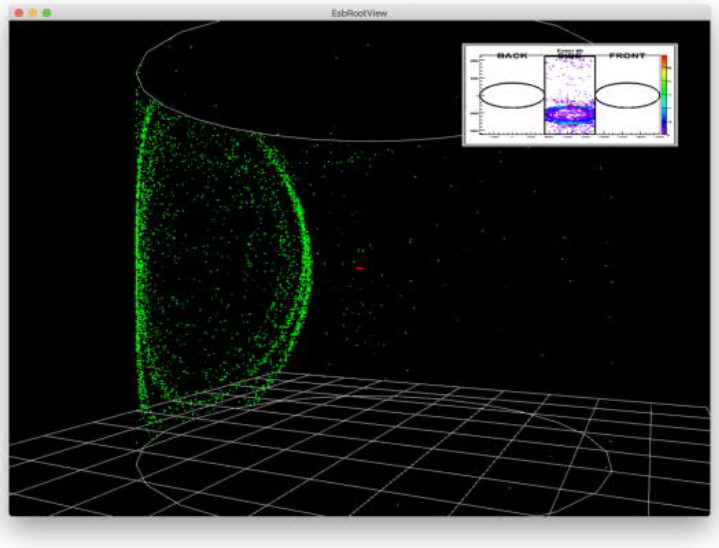


Figure 6.48: Overall view of a single far-detector tank with indicated dimensions.



Two 270 kton fiducial voume water Cherenkov detector

A muon Cherenkov ring

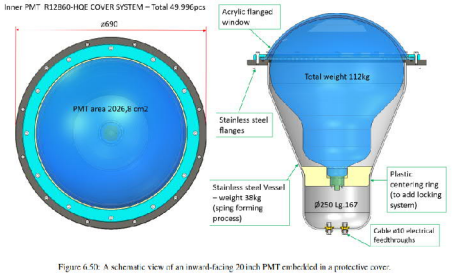
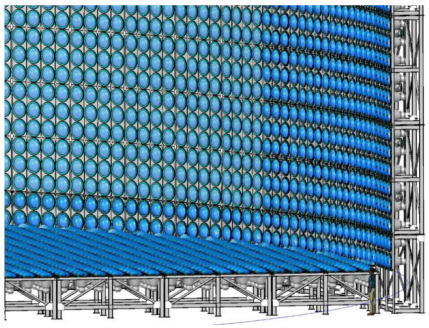
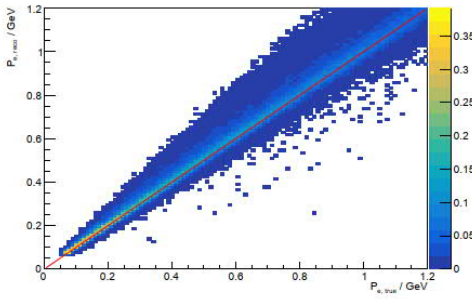


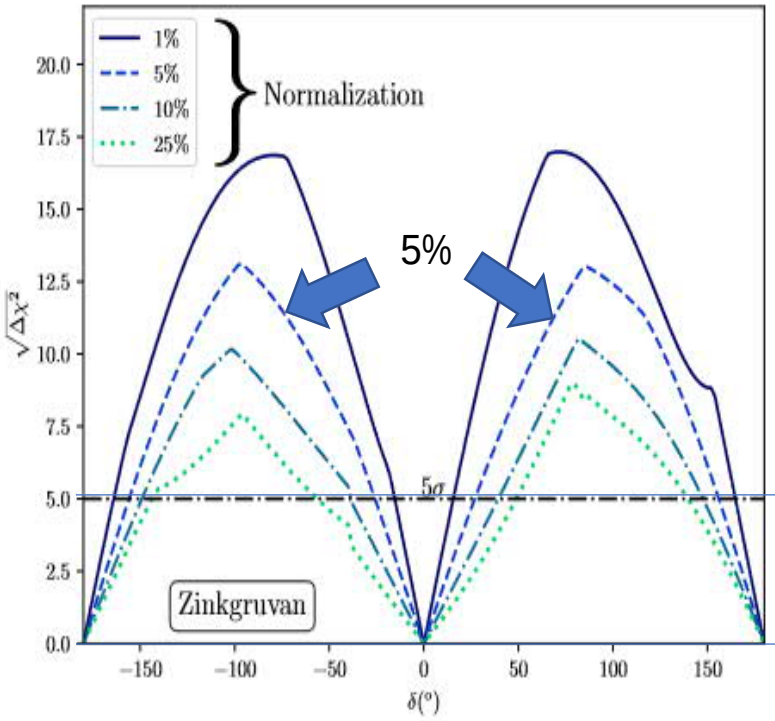
Figure 6.50: A schematic view of an inward-facing 20 inch PMT embedded in a protective cover.



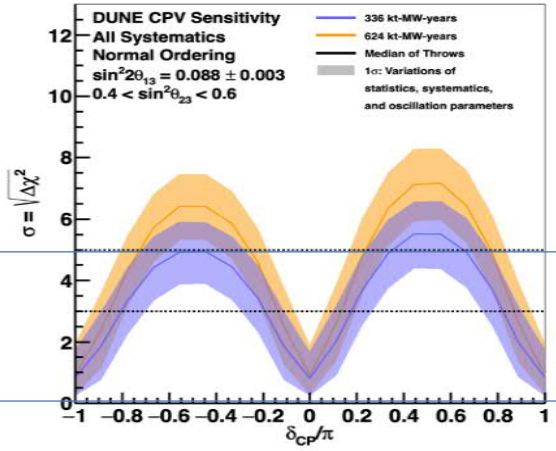


For Cherenkov imagies in the Far Detector see https://drive.google.com/drive/folders/1DidkJRA05GJtm0vFSqpfpCTAooNWAv22

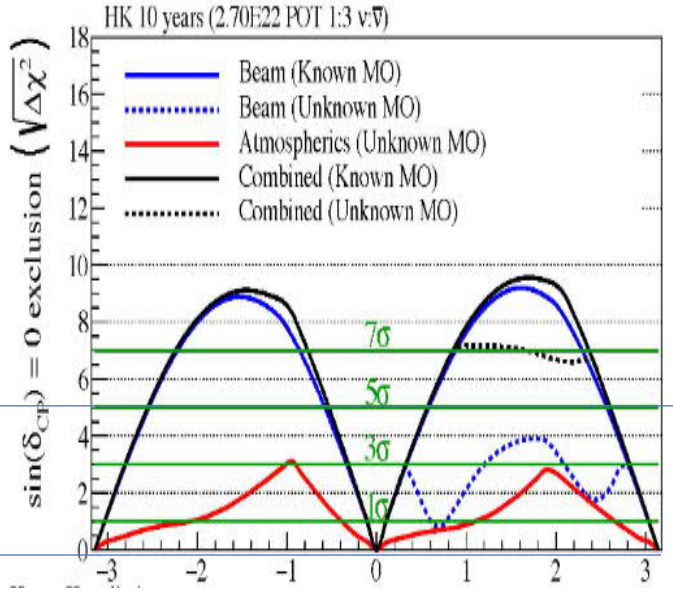
ESSnuSB performance in the international context – CPV discovery



ESSnuSB March 2022 with 5% normalization error

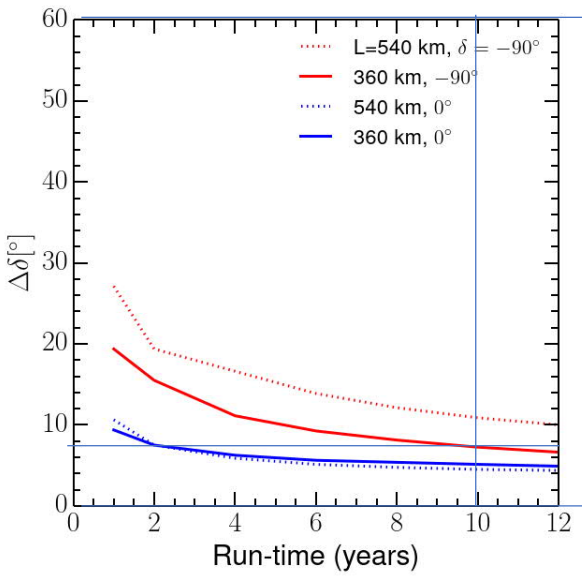


DUNE Snowmass March 2022

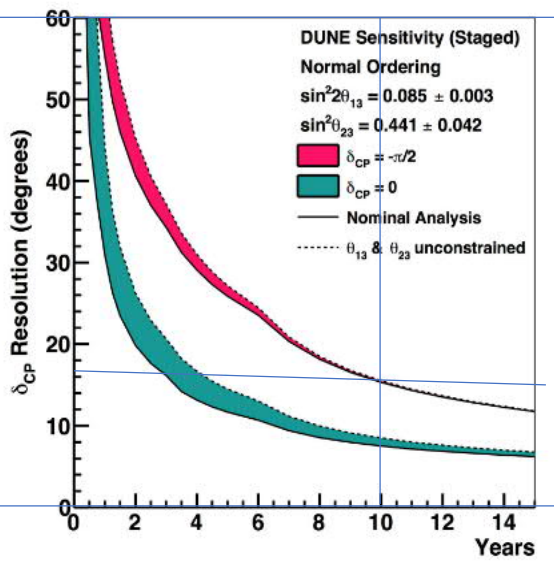


HyperKamokande Snowmass March 2022

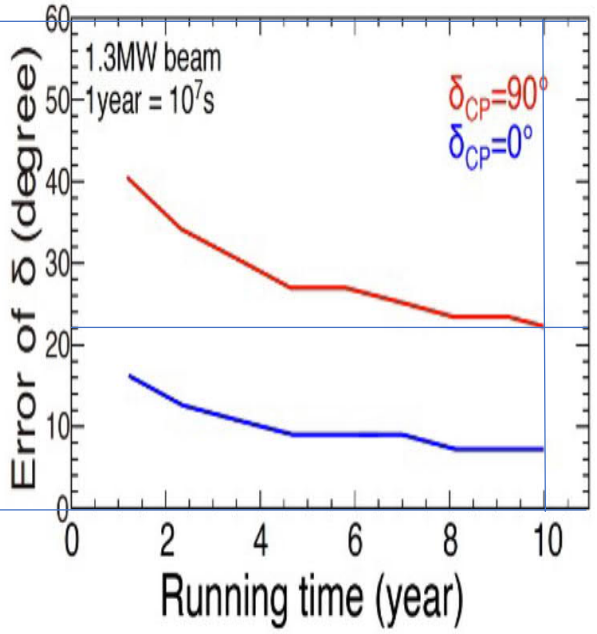
ESSnuSB performance in the international context – CPV resolution



ESSnuSB March 2022 with 5% normalization error

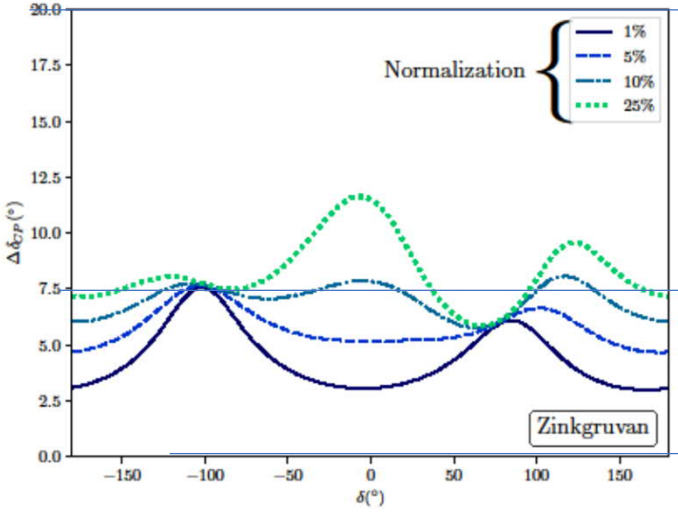


DUNE Snomass March 2022

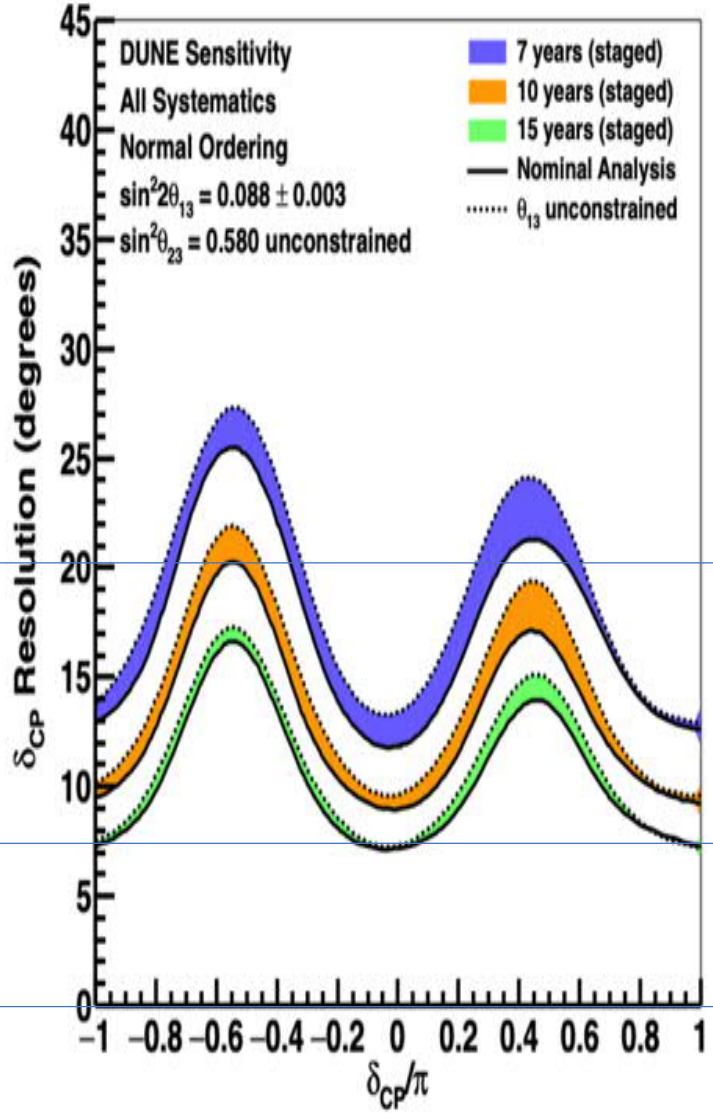


HyperKamokandeSnowmass March 2022

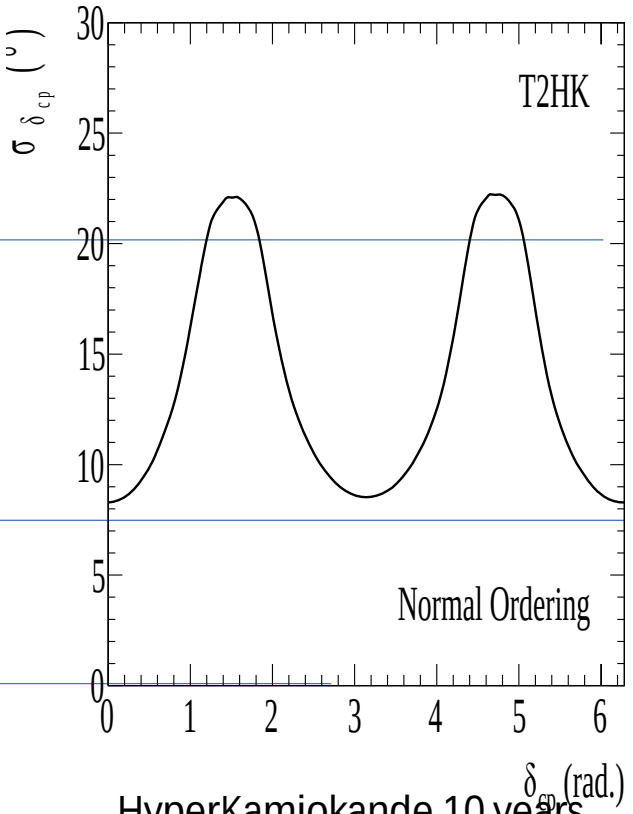
ESSnuSB performance in the international context – precision in δ_{CP}



ESSnuSB 10 years



DUNE 10 years yellow curve



HyperKamiokande 10 years

ESSnuSB Cost Esimate

Total Cost 1’382 M€

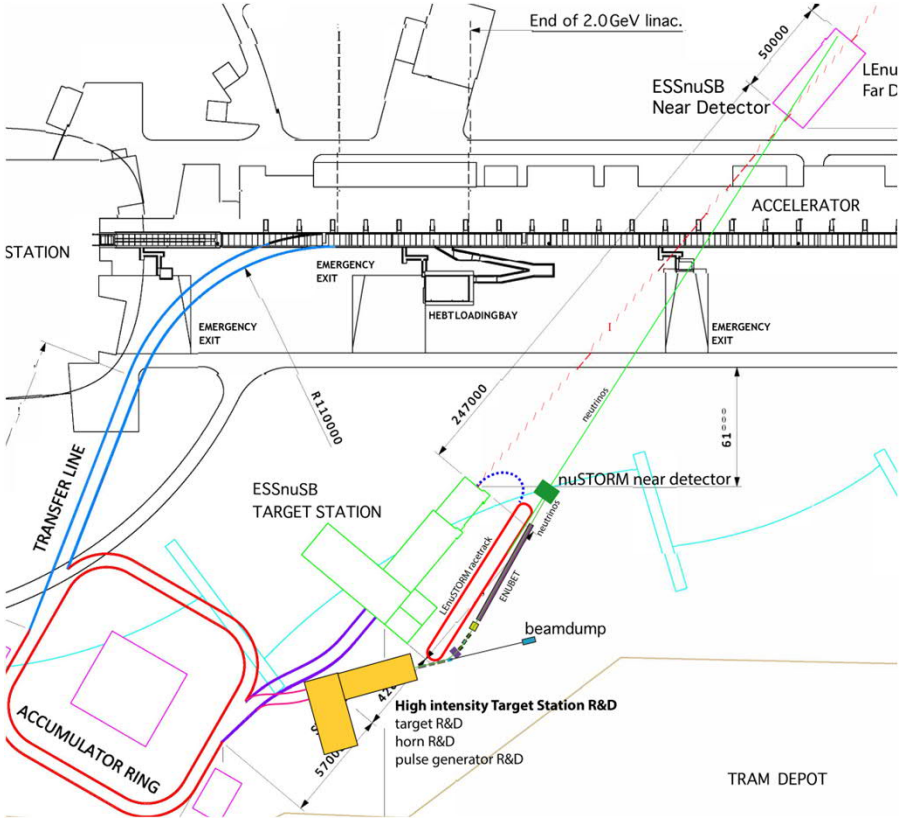
The ca 75’000 20 inch PMTs and the excavation of the cavern for the two Far Detectors represents 67% of the total cost.

The cost of civil engineering on the ESS site is not included. A cost estimate of this civil engineering will require a detailed study of the implementation of the components on the ESS site, that will be made only in the next phase of the study.

Item	Sub-item	Cost (M€)	Cost (%)
Linac Upgrade	Ion Source and Low-Energy Beam Transport (LEBT)	5.00	0.36%
	Radio-Frequency Quadrupole	6.90	0.50 %
	Medium Energy Beam Transport (MEBT) Upgrade	3.00	0.22%
	Drift-Tube Linac with BPMs, BCMs	13.40	0.97%
	High-Beta Linac (HBL) Upgrade	10.40	0.75%
	33 Modulator Upgrades	3.50	0.25%
	8 New Modulators	9.00	0.65%
	15 Grid-Modulator Transformers	5.60	0.41%
	11 Grid-Modulator Transformers Retrofitted	0.50	0.04%
	26 Solid-State Spoke Amplifiers	26.00	1.88%
	New Klystrons for upgraded HBL	12.10	0.88%
	Remaining Klystron Refurbishment/Replacement	25.20	1.82%
	Cryogenics, Water Cooling, Civil Eng.	12.00	0.87%
	Total	**132.60**	**9.59%**
Accumulator	**Item**	**Cost (M€)**	**Cost (%)**
	DC Magnets and Power Supplies	50.00	3.62%
	Injection system	11.00	0.80%
	Extraction System	7.00	0.51%
	RF Systems	16.00	1.16%
	Collimation	8.00	0.58%
	Beam Instrumentation	19.00	1.37%
	Vacuum System	24.00	1.74%
	Control System	30.00	2.17%
	Total	**165.00**	**11.94%**
Target Station	**Item**	**Cost (M€)**	**Cost (%)**
	Target Station	32.00	2.32%
	Proton Beam Window System	5.20	0.38%
	PSU + Striplines	5.40	0.39%
	Target and Horn Exchange System	40.42	2.92%
	Facility Building Structure	26.60	1.92%
	General System and Services	21.80	1.58%
	Total	**131.42**	**9.51%**
Detectors	**Item**	**Cost (M€)**	**Cost (%)**
	Emulsion Detectors	2.00	0.14%
	Super Fine-Grained Detector	5.49	0.40%
	Near Water Cherenkov Detector	25.22	1.82%
	Far Water Detector	399.35	28.89%
	Underground Cavern Excavations	521.15	37.70%
	Total	**953.21**	**68.93%**
Grand Total		**1382.23**	**100.00%**

Continuation of design studies 2023-2026

ESSnuSB+ proposal granted by EU 26/07/2022 with 3 M€



1. Design of a racetrack storage ring for low energy muons produced with a beam from the ESS linac.
2. Design a transfer system from the initial collection and extraction of pions behind the target station, up to the injection point.
3. Design a transfer line from the ESSvSB ring-to-switchyard transfer line to the nuSTORM target.
4. Design an injection scheme for the racetrack storage ring
5. Design a Monitored Neutrino Beam (low energy ENUBET)
6. Optimize the performance of the ESSvSB accelerator complex

Cross-section measurements with:

- Low Energy nuSTORM: $\pi \longrightarrow \mu \longrightarrow e+\nu_\mu+\nu_e$
- Low Energy ENUBET: $\pi \longrightarrow \mu+\nu_\mu$

ESSvSB+

26/07/2022

Title of Horizon Europe EU Proposal: Study of the use of the ESS facility to accurately measure the neutrino cross-sections for ESSvSB leptonic CP violation measurements and to perform sterile neutrino searches and astroparticle physics.

Acronym of Proposal: ESSvSB+

Participant no.	Participant organisation name	Part. short name	Country
1 (Coordinator)	Centre National de la Recherche Scientifique	CNRS	France
2	Université de Strasbourg	UNISTRA[1]	France
3	Rudjer Boskovic Institute	RBI	Croatia
4	Tokai National Higher Education and Research System, National University Corporation	NU[2]	Japan
5	Uppsala Universitet	UU	Sweden
6	Lunds Universitet	ULUND	Sweden
7	European Spallation Source ERIC	ESS	Sweden
8	Kungliga Tekniska Hoegskolan	KTH	Sweden
9	Universitaet Hamburg	UHH	Germany
10	University of Cukurova	CU	Turkey
11	National Center for Scientific Research "Demokritos"	NCSRD	Greece
12	Aristotelio Panepistimio Thessalonikis	AUTH[1]	Greece
13	Sofia University St. Kliment Ohridski	UniSofia	Bulgaria
14	Lulea Tekniska Universitet	LTU	Sweden
15	European Organisation for Nuclear Research	CERN	IEIO[3]
16	Universita degli Studi Roma Tre	UNIROMA3	Italy
17	Universita degli Istudi di Milano-Bicocca	UNIMIB	Italy
18	Istituto Nazionale di Fisica Nucleare	INFN	Italy
19	Universita degli Istudi di Padova	UNIPD[1]	Italy
20	Consorcio para la construccion, equipamiento y explotacion de la sede espanola de la fuente Europea de neutrones por espalacion	ESSB	Spain

[1] Affiliated Partner
[2] Associated Institute
[3] International European Interest Organisation

Excellent supporting letter from the ESS director

Schedule for the 2nd generation ESS-based neutrino Super Beam ESSnuSB

2012: Inception of the project

2016-2019: Beginning of COST Action EuroNuNet

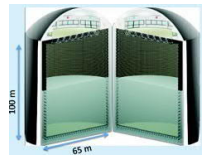
2018: Beginning of ESSνSB Design Study (EU-H2020)

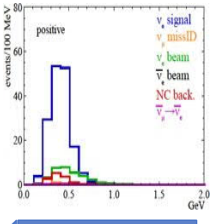
2022: End of ESSνSB Design Study, preliminary costing and CDR

2023-2026: Continuation of Design Study, final costing and an TDR to ESFRI

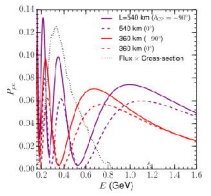
2027-2028: Preconstructi on Phase, International Agreements

2029-2035: Construction o the facility an detectors, including commissionir





2036-: Start of data taking



Nucl. Phys. B 885 (2014) 127

Summary

- The ESS neutron spallation source currently under construction in Lund can be the basis also for a world-unique neutrino facility, ESSvSB, which in a first conceptual design study has been proven to have very high physics performance and potential.
- With ESSvSB 5σ discovery potential for CP violation can be reached over 70% of the δ_{CP} range and δ_{CP} can be measured with an error less than 8° independently of its value.
- Complementary studies of this project will be made in a second Design Study 2023-2026 enabling in particular:
  - -Precise neutrino cross-section measurements
  - -Sterile neutrino searches
  - -SuperNova and relic neutrinos measurements, proton life-time…
- Kick-off 17-18 January 2023 at the ESS site of the 4-years ESSnuSB+ EU funded continuation to produce an ESSnuSB Technical Design Report by 2026

Thank you