ESS NEUTRINO SUPER BEAM
cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY
Funded by the Horizon 2020 Framework Programme of the European Union

ESS NEUTRINO SUPER BEAM

Orsay, le 20 janvier 2020

M. Dracos, E. Bouquerel, CNRS-IPHC,
on behalf of the ESSnuSB project

cnrs IN2P3 Les deux infinis
IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG
Université de Strasbourg

The European Consortium working on the ESSvSB project

2 projets:

- COST Action **EuroNuNet** (CA15139)

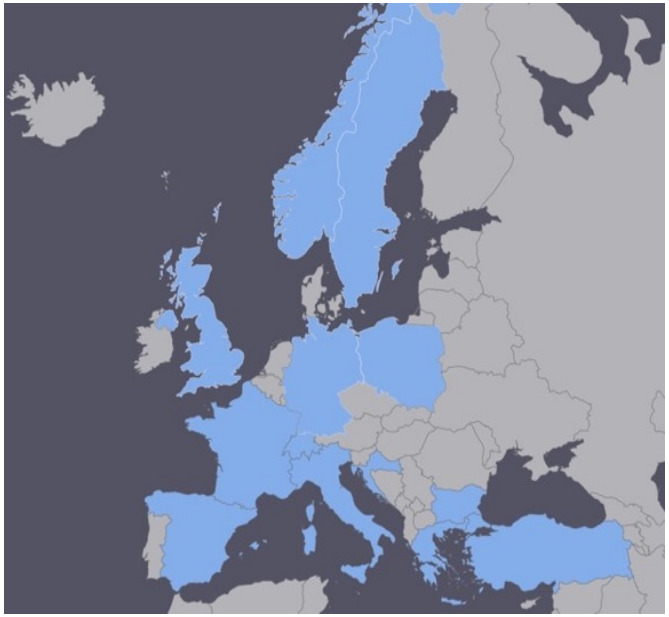
- EU-H2020 Design Study **ESSvSB**

EuroNuNet

- COST Action for networking: CA15139 (2016-2020)
  - **EuroNuNet** : *Combining forces for a novel European facility for neutrino-antineutrino symmetry violation discovery* (http://www.cost.eu/COST_Actions/ca/CA15139)

The members are countries which signed the Action MoU

- **Objectifs d'EuroNuNet**:
  - Agréger la communauté de la physique des neutrinos en Europe pour étudier de nouveaux concepts sur la production des neutrinos,
  - Avoir un impact sur ceux qui décident des priorités en matière de Physique des Hautes énergies (+ organismes de financement) dans l'approche d'une découverte expérimentale de la violation CP.
  - 13 participating countries



http://euronunet.in2p3.fr/

Add a neutrino facility on top of the ESS neutron one

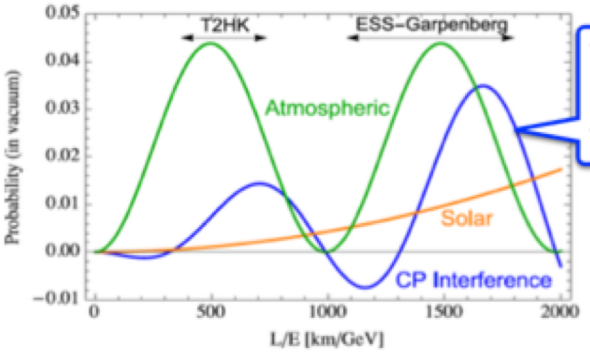
ESSnuSB is a unique opportunity to observe the 2nd oscillation maximum.

5 MW proton driver at Lund

$\langle E_\nu \rangle = 0.3\text{-}0.4[\mathrm{GeV}]$

$L \simeq 400\text{-}600[\mathrm{km}]$ for 2nd max

To compensate the loss of the flux due to the long baseline, a megaton-class detector is required — MEMPHYS.



The 2nd max contains more info of CP than the 1st max.

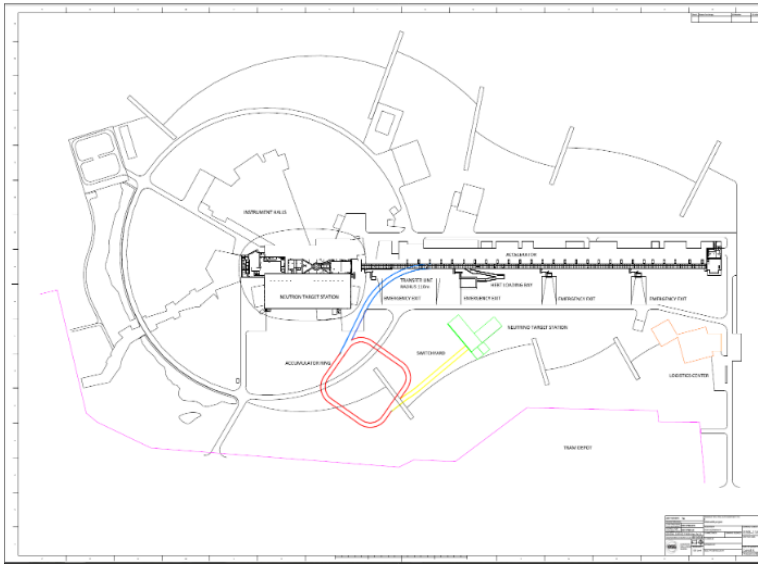
*Components of the vac. osc. probability as a function of L/E.

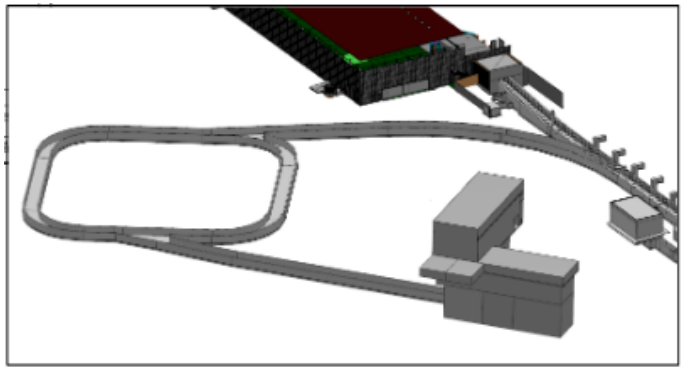
$P(\nu_\mu \to \nu_e)$ =Atm.+Sol.+CP

Add a neutrino facility on top of the ESS neutron one

- Linac modifications: double the rate (14 Hz → 28 Hz),
- Accumulator (C~400 m) needed to compress to few μs the 2.86 ms proton pulses,
- Target station (studied in EUROv),
- Underground near and far detectors.

Also…the neutron program must not be affected and if possible synergetic modifications.



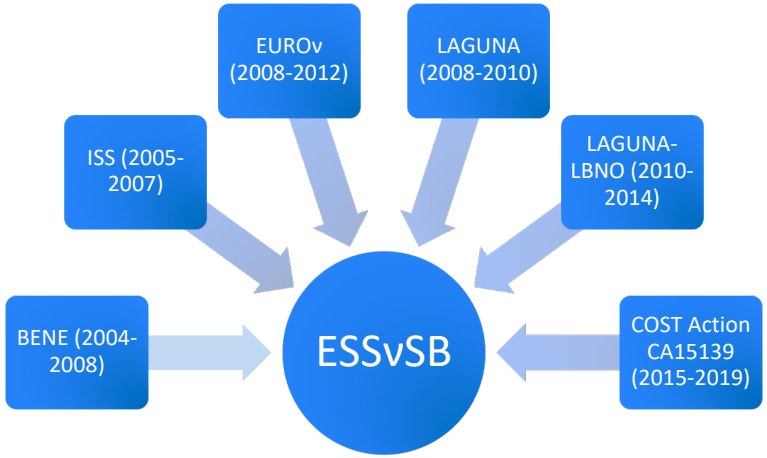


Rasmus Johansson and Nick Gazis

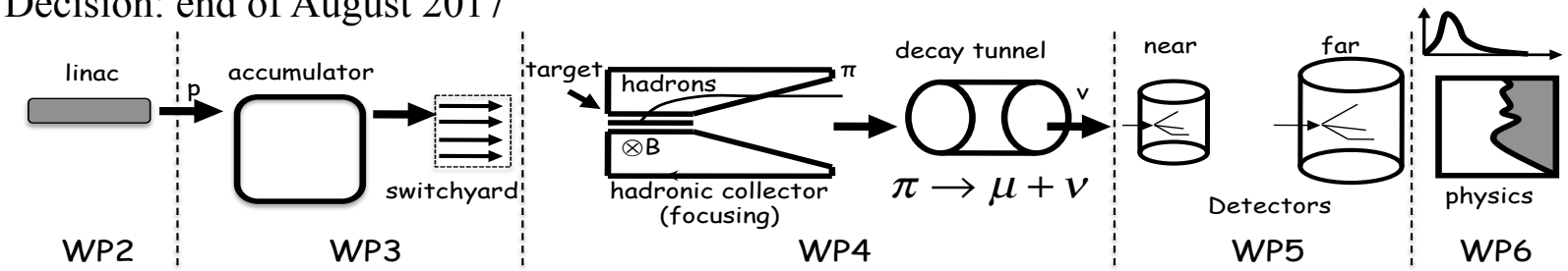
The H2020 ESSvSB Design Study

- A **H2020** EU **Design Study** has been submitted March 2017 (Call INFRADEV-01-2017)
- **Title of Proposal**: Discovery and measurement of leptonic CP violation using an intensive neutrino Super Beam generated with the exceptionally powerful ESS linear accelerator.
- **Duration: 4 years**
- **Total cost: 4.7 M€**
- **Requested budget: 3 M€**

cnrs IN2P3 Les deux infinis
leading institute



- 15 participating institutions from 11 European countries including CERN and ESS
- 6 Work Packages
- Decision: end of August 2017



ESSvSB PROJECT: GENERAL INFORMATION

- Starting date: 01/01/2018
- Ending date: 31/12/2021
- Duration: 48 Months
- Grant Agreement signature: 22/11/2017
- Estimated cost: 4,671,583.68€
- Requested EU contribution: 2,999,018.00€
- Kick-off meeting: 15 January 2018, Lund (ESS)
- 80% of the budget already received

Grant Agreement number: 777419 — ESSnuSB — H2020-INFRADEV-2016-2017/H2020-INFRADEV-2017-1

Associated with document Ref. Ares(2017)5226555 - 25/10/2017

EUROPEAN COMMISSION
DIRECTORATE-GENERAL RESEARCH & INNOVATION
Open Innovation and Open Science
Research infrastructure

GRANT AGREEMENT

NUMBER — 777419 — ESSnuSB

This **Agreement** ('the Agreement') is **between** the following parties:

on the one part,

the **European Union** ('the EU'), represented by the European Commission ('the Commission'), represented for the purposes of signature of this Agreement by Head of Unit, DIRECTORATE-GENERAL RESEARCH & INNOVATION , Open Innovation and Open Science , Administration and finance, Pascale CID,

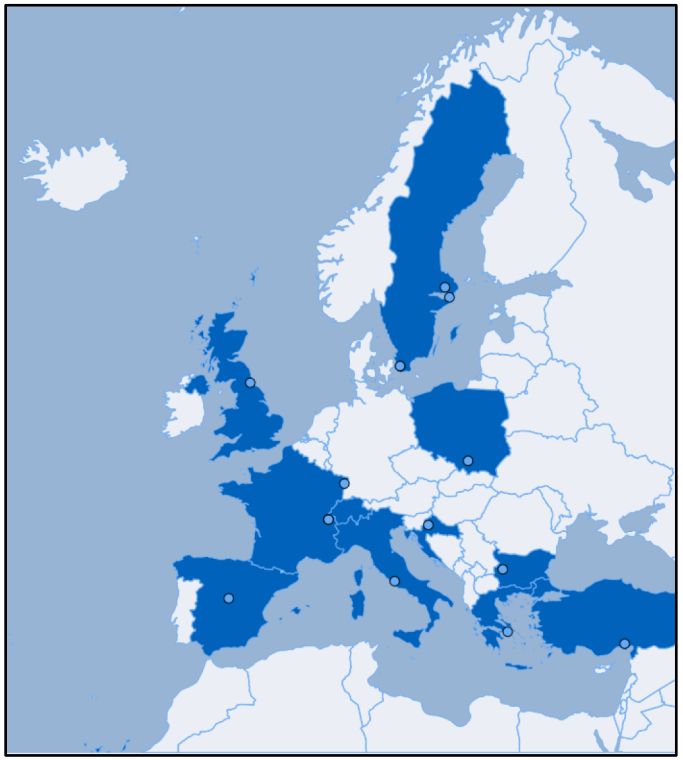
and

ESSnuSB Structure: participating institutions/organisations

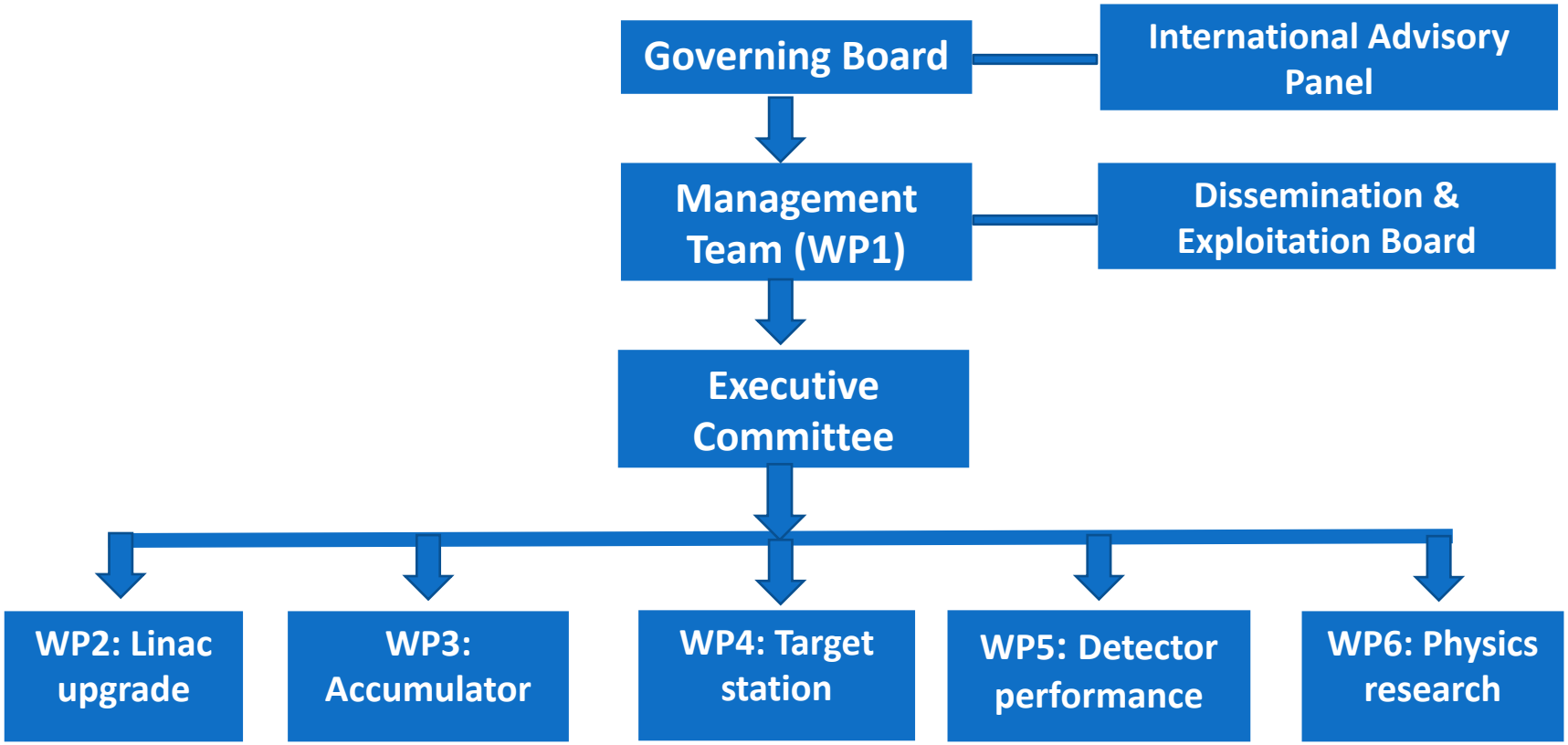
15 participating organisations within 11 countries

List of ESSnuSB Participating Institutions / Organisations

#	Institutions / organisations name	Accronym	Country
1	Centre National de la Recherche Scientifique	CNRS	France
2	University of Uppsala	UU	Sweden
3	Kungliga Tekniska Hoegskolan	KTH	Sweden
4	European Spallation Source Eric	ESS	Sweden
5	University of Cukurova	CU	Turkey
6	Universidad Autonoma de Madrid	UAD	Spain
7	National Center for Scientific Research "Demokritos"	DEMOKRITOS	Greece
8	Instituto Nationale di Fisica Nucleare	INFN	Italy
9	Ruder Boskovi Instgitute	RBI	Croatia
10	Sofiiski Universitet Sveti Kliment Ohridski	UniSofia	Bulgaria
11	Lunds Universitet	ULUND	Sweden
12	Akademia Gorniczo-Hutnicza Im. Stanislawa Staszica w Krakowie	AGH / AGH-UST	Poland
13	European Organization for Nuclear Resarch	CERN	Switzerland
14	University of Geneva	UNIGE	Switzerland
15	University of Durham	UDUR	United Kingdom



ESSnuSB STRUCTURE: ORGANISATION CHART



ESSnuSB STRUCTURE: LIST OF PARTICIPANTS

Governing Board (GB)

Chair: Tommy Ohlsson (KTH, SE)
Project Coordinator: Marcos Dracos (CNRS-IPHC)
Scientific Leader: Tord Ekelof (UU, SE)
Members
- Sebastien Bousson (CNRS-IN2P3, FR)
- Elian Bouquerel (CNRS-IPHC, FR)
- Mats Lindroos (ESS, SE)
- Aysesl Kayis Topaksu (CU, TR)
- Enrique Martinez-Fernandez (UAM, ES)
- Georgios Fanourakis (NCSRD, GR)
- Francesco Terranova (INFN, IT)
- Mauro Mezzetto (INFN, IT)
- Budimir Klicek (RBI, HR)
- Mariyan Bogomilov (UNISOFIA, BG)
- Joakim Cederkall (ULUND, SE)
- Lis Jerzy (AGH, PL)
- Jean-Pierre Delahaye (CERN, CH)
- Alain Blondel (UniGe, CH)
- Silvia Pascoli (UDUR, UK)

International Advisory Panel (IAP)

Chair: to be nominated by the panel
Accelerator expert: Jingyu Tang (IHEP)
Compressor ring expert: Shinji Machida (RAL)
Target Station expert: Chris Densham (RAL)
Physics experts: Eligio Lisi (INFN, IT)
Detector expert: Alexander Olshevskij (JINR)

Executive Committee (EC)

Scientific Leader: Tord Ekelof (KTH)
Project Coordinator: Marcos Dracos (CNRS-IPHC)
Technical Advisor: Ilias Efthymiopoulos (CERN)
Work Package Leaders (Coordinators)
- **WP2:** Mamad Eshraqi (ESS, SE)
- **WP3:** Maja Olvegard (UU, SE)
- **WP4:** Piotr Cupial (AGH, PL)
- **WP5:** Roumen Tsenov (UniSofia, BG)
- **WP6:** Enrique Martinez Fernandez (UAM, ES)

WP1 - Management Team (MT)

Scientific Leader: Tord Ekelof (KTH, SE)
Project Coordinator: Marcos Dracos (CNRS-IPHC, FR)
Technical Advisor: Ilias Efthymiopoulos (CERN, CH)

Dissemination & Exploitation Board (DEB)

Scientific Leader: Tord Ekelof (UU, SE)
Project Coordinator: Marcos Dracos (CNRS-IPHC, FR)
Members
- Colin Carlile (UU, SE)
- Kjell Grundström (IUCDarlana, SE)
- Elian Bouquerel (CNRS-IPHC, FR)
- Georgios Fanourakis (Demokritos, GR)
- Aysel Kayis Topaksu (CU, TR)

http://essnusb.eu/

Total Man power

Participant	WP1	WP2	WP3	WP4	WP5	WP6	Total
CNRS	60.00	6.00	31.00	69.00	0.00	0.00	**166.00**
UU	6.00	18.00	72.20	2.00	3.40	2.40	**104.00**
ESS	0.00	66.80	0.00	0.00	0.00	0.00	**66.80**
CERN	0.00	1.00	13.00	5.00	0.00	0.00	**19.00**
KTH	0.00	0.00	0.00	0.00	0.00	26.40	**26.40**
UAM	0.00	0.00	0.00	0.00	0.00	32.00	**32.00**
AGH	0.00	0.00	0.00	60.00	0.00	0.00	**60.00**
UniSofia	0.00	0.00	0.00	0.00	43.00	0.00	**43.00**
LU	0.00	0.00	0.00	0.00	25.00	2.00	**27.00**
INFN	0.00	0.00	0.00	0.00	0.00	2.40	**2.40**
UDUR	0.00	0.00	0.00	0.00	0.00	1.00	**1.00**
RBI	0.00	0.00	0.00	0.00	20.00	0.00	**20.00**
NCSRD	0.00	0.00	0.00	0.00	7.00	5.00	**12.00**
CU	0.00	0.00	0.00	0.00	12.00	0.00	**12.00**
UniGe	0.00	0.00	0.00	2.75	8.25	0.00	**11.00**
Total	**66.00**	**91.80**	**116.20**	**138.75**	**118.65**	**71.20**	**602.60**

= 27.5% cnrs IN2P3 Les deux infinis IPHC and IJCLAB (IPNO)

Person	Months	Months	Months	Months	Total	Fraction	WP1	WP2	WP3	WP4	WP5	WP6	Total
1. CNRS	1-12	13-24	25-36	37-48	48 months								
M. Dracos	6.00	6.00	6.00	6.00	24.00	0.50	12.00	0.00	7.00	5.00	0.00	0.00	24
J.Wurtz	2.00	2.00	2.00	2.00	8.00	0.17	0.00	0.00	0.00	8.00	0.00	0.00	8
P. Poussot	4.00	4.00	4.00	4.00	16.00	0.33	0.00	0.00	0.00	16.00	0.00	0.00	16
E. Bouquerel	6.00	6.00	6.00	6.00	24.00	0.50	0.00	0.00	24.00	0.00	0.00	0.00	24
C. Schwab	0.50	0.50	0.50	0.50	2.00	0.04	0.00	0.00	0.00	2.00	0.00	0.00	2
V. Zeter	0.50	0.50	0.50	0.50	2.00	0.04	0.00	0.00	0.00	2.00	0.00	0.00	2
E. Baussan	3.00	3.00	3.00	3.00	12.00	0.25	0.00	0.00	0.00	12.00	0.00	0.00	12
S. Bousson (IPNO)	1.00	2.00	2.00	1.00	6.00	0.13	0.00	6.00	0.00	0.00	0.00	0.00	6
Loris D'Alessi (PostDoc)	0.00	12.00	12.00	0.00	24.00	0.50	0.00	0.00	0.00	24.00	0.00	0.00	24
ML. Schneider	12.00	12.00	12.00	12.00	48.00	1.00	48.00	0.00	0.00	0.00	0.00	0.00	48
Total	35.00	48.00	48.00	35.00	166.00	3.46	60.00	6.00	31.00	69.00	0.00	0.00	166
							= 36%	4%	19%	41%			

Postdoc RECRUITMENT – OVERALL VIEW

POSTDOC DISTRIBUTION IN THE COURSE OF THE PROJECT

PERIOD		1-12	13-24	25-36	37-48	48 month	WP1	WP2	WP3	WP4	WP5	WP6	Total
CNRS	Postdoc1	0,00	6,00	12,00	6,00	24,00	0,00	0,00	0,00	24,00	0,00	0,00	24,00
UPPSALA	Postdoc1	6,00	12,00	12,00	6,00	36,00	0,00	0,00	36,00	0,00	0,00	0,00	36,00
KTH	Postdoc1	0,00	6,00	6,00	0,00	12,00	0,00	0,00	0,00	0,00	0,00	12,00	12,00
ESS	Postdoc1	6,00	12,00	6,00	0,00	24,00	0,00	24,00	0,00	0,00	0,00	0,00	24,00
ESS	Postdoc2	0,00	6,00	12,00	12,00	30,00	0,00	30,00	0,00	0,00	0,00	0,00	30,00
UAM	Postdoc1	0,00	6,00	12,00	6,00	24,00	0,00	0,00	0,00	0,00	0,00	24,00	24,00
UNISOFIA	Postdoc1	3,00	12,00	9,00	0,00	24,00	0,00	0,00	0,00	0,00	24,00	0,00	24,00
LUND	Postdoc1	0,00	6,00	6,00	0,00	12,00	0,00	0,00	0,00	0,00	12,00	0,00	12,00
AGH	Postdoc1	4,00	10,00	10,00	0,00	24,00	0,00	0,00	0,00	24,00	0,00	0,00	24,00
TOTAL		19,00	76,00	85,00	30,00	210,00	0,00	54,00	36,00	48,00	36,00	36,00	210,00

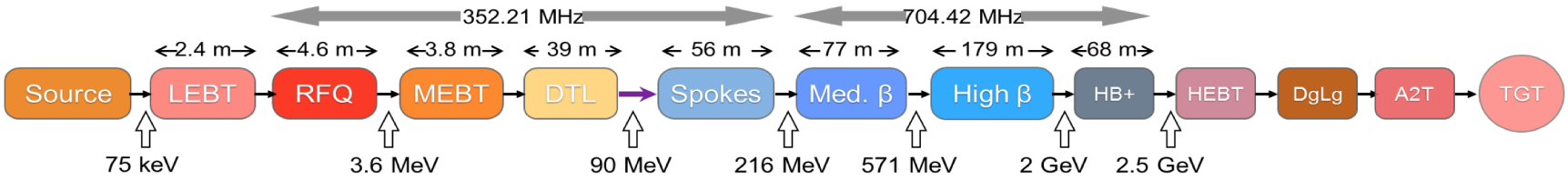
Almost all of them engaged

20 Deliverables & 18 Milestones

Delivrable number	Delivrable title	Lead Beneficiary	Due date in months
D1.1	Data Management Plan	1-CNRS	6
D1.2	Initial facility parameters	1-CNRS	6
D2.1	Requirements for the linac	4-ESS	8
D5.1	Near detector requirements	10-UNISOFIA	8
D6.1	Physics performance according to initial parameters	6-UAM	12
D2.2	H- source design, integration into ESS and RF upgrade studies	4-ESS	15
D3.1	Accumulator operation scheme	2-UU	24
D4.1	Optimized design of the magnetic horn	12-AGH/AGH-UST	24
D5.2	Mine evaluation for the far detector	10-UNISOFIA	24
D6.2	Physics performance after first optimisations	6-UAM	24
D4.2	Evaluation of an alternative hadron collector	12-AGH/AGH-UST	28
D2.3	Beam losses and activation	4-ESS	30
D6.3	Physics performance and comparison with other pro	6-UAM	32
D3.2	Transfer lines layout and design, extraction and switchyard design	2-UU	36
D4.3	Design of the pulse generator and o fthe horn cooling system	12-AGH/AGH-UST	36
D5.3	Design of the near detector	10-UNISOFIA	36
D1.3	Performance, cost and safety evaluation of the facili	1-CNRS	42
D5.4	Design of the far detector and its performance evalu	10-UNISOFIA	42
D6.4	Final physics performance	6-UAM	42
D2.4	Conceptual design of the ESS RF power upgrade	4-ESS	45
D4.4	Design of the target station	12-AGH/AGH-UST	45

Milestone number	Milestone title	Lead Beneficiary	Due date in months
MS1	Review of 1st year achievements, deliverables & costs	1-CNRS	14
MS2	Linac report	4-ESS	12
MS3	Update physics potential	6-UAM	12
MS4	Evaluation of accumulator requirements	2-UU	12
MS5	Design o fthe hadron collecxtion device	12-AGH/AGH-UST	18
MS6	Accumulator lattice design	2-UU	18
MS7	First estimation of neutrino beam intensity	12-AGH/AGH-UST	24
MS8	Design concept of the near detector	10-UNISOFIA	24
MS9	Review on interim milestones, deliverables & costs	1-CNRS	26
MS10	Specification of H-- beam handling system complete	4-ESS	32
MS11	Review of systematic errors	6-UAM	32
MS12	Physics performance with update of fluxes	6-UAM	36
MS13	Review of 3rd year milestones, deliverables and costs	1-CNRS	38
MS14	Linac modifications	4-ESS	40
MS15	Full simulation of tghe accumulation ring	2-UU	40
MS16	Choice of optimal baseline scenario	6-UAM	40
MS17	Final design of target station	12-AGH/AGH-UST	42
MS18	Cost and performance evaluation complete	1-CNRS	48

Work Package 2: Linac



D2.1 Requirements for the linac

- **Accelerator tunnel**:
  - H^- source, low energy beam transport, RFQ and medium energy beam transport plus a switch dipole.
  - To reach 2.5 GeV, 8 additional cryomodules of the High Beta type.
  - Steerer magnets and associated power supplies should be exchanged with pulsed ones.
- **Klystron gallery**:
  - Klystron collectors should either be exchanged for added average power or the whole klystrons could be exchanged against more powerful models.
  - Additional capacitor chargers.
- **ESS site**:
  - An additional main electrical station
  - Three additional electrical substations
  - HV cable trenches and pulling of additional HV cables from the main station towards the new substations.

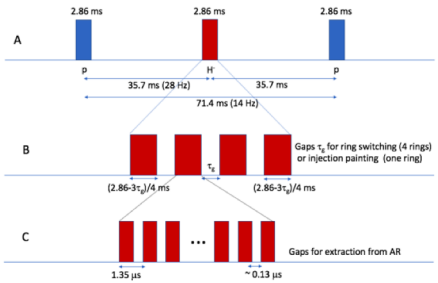
Parameter	ESS	Upgrade
Ion	p	p + H^-
Average beam power	5 MW	10 MW
Kinetic energy	2 GeV	2.5 GeV
Macro pulse current	62.5 mA	50 mA
Macro pulse length	2.86 ms	>2.86 ms
Subpulse length	N/A	~0.72 ms
Pulse repetition rate	14 Hz	28 Hz
Beam Duty cycle	4%	8 %
Linac length	352.5 m	352.5 + ca 70 m

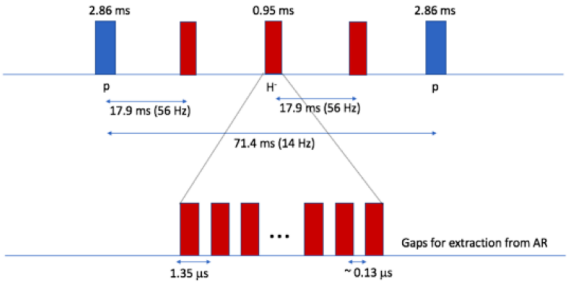
Work Package 3: Accumulator

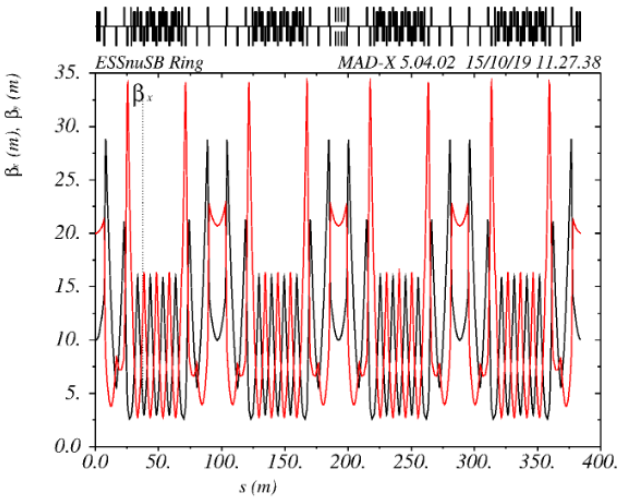
The accumulator is needed to compress to less than few μs the 2.86 ms proton pulses, affordable by the magnetic horn (350 kA, power consumption, Joule effect), but also keeping a reasonable size of the ring.

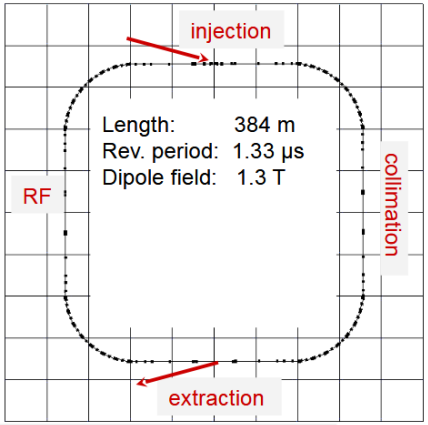
Objectives:

- Study the accumulator operation scheme
- Design of the accumulator ring, its transfer line and its extraction kicker
- Study the stripping of H-
- Design of the ejection switchyard



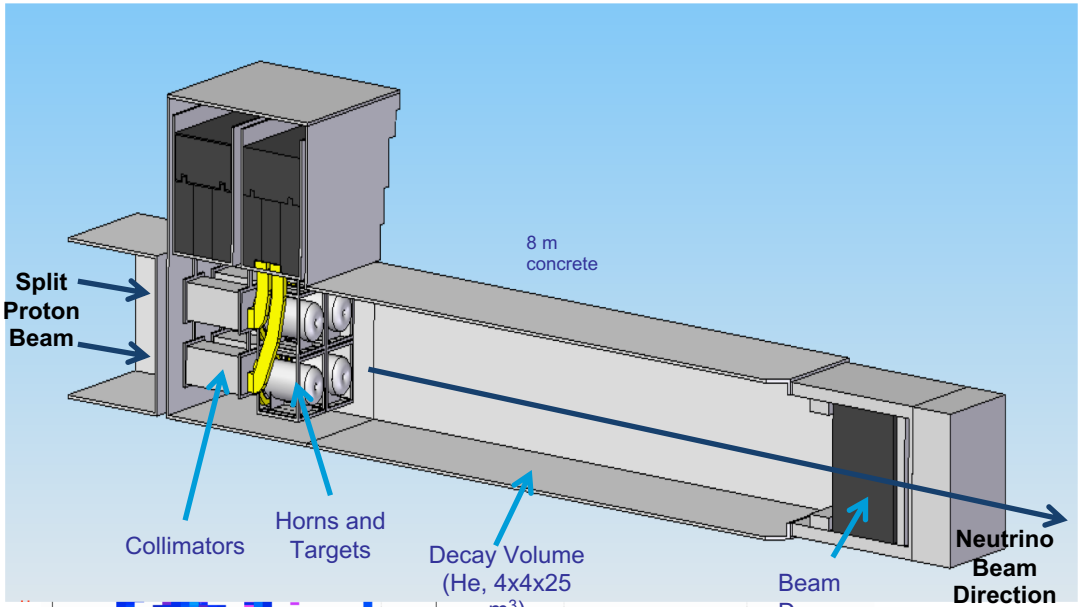






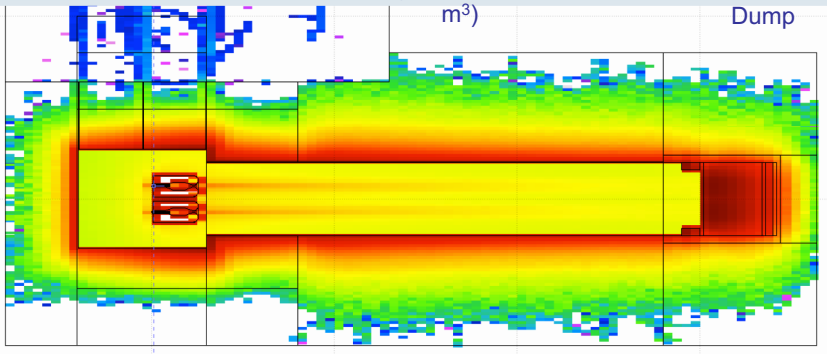
Horst Schönauer, CERN

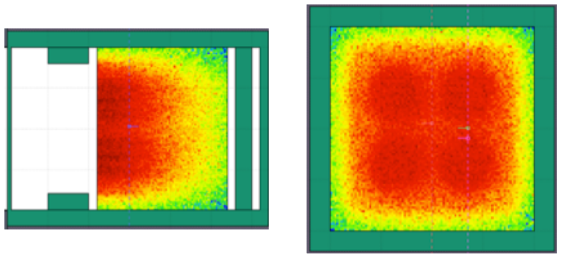
Work Package 4: Target Station



Objectives:

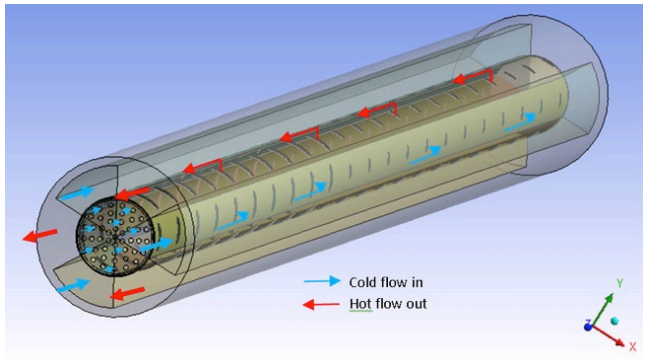
- Adapt a target station to the ESSnuSB requirements (the target/hadron collector(horn)/power supply unit)
- Optimize the facility structure
- Simulate the neutrino beam



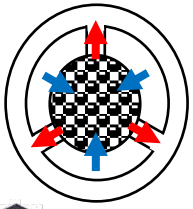


Work Package 4: Target Station

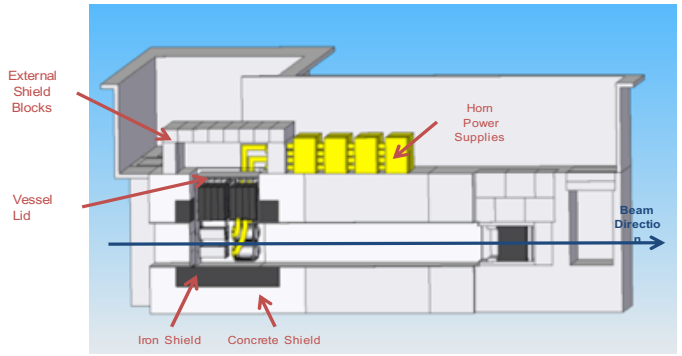
Packed bed canister in symmetrical transverse flow configuration (titanium alloy spheres)

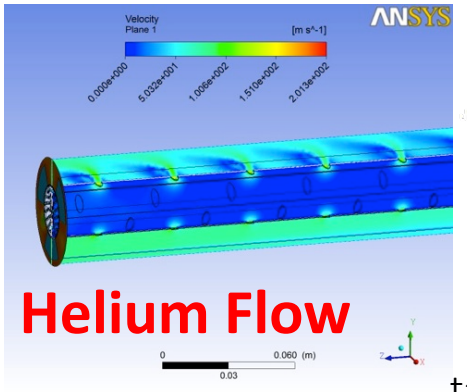


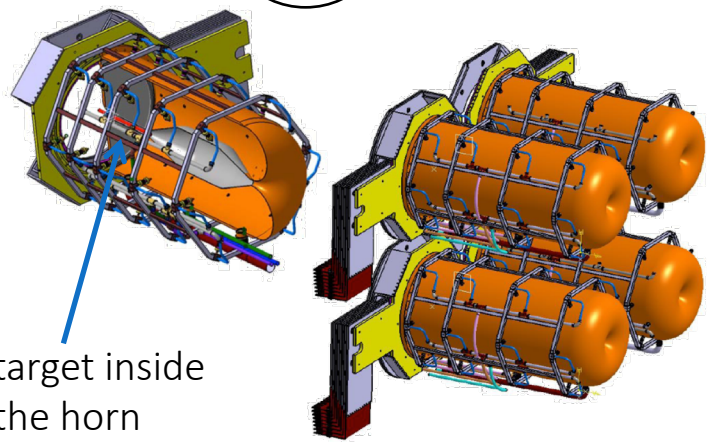
4-target/horn system to mitigate the high proton beam power (5 MW)



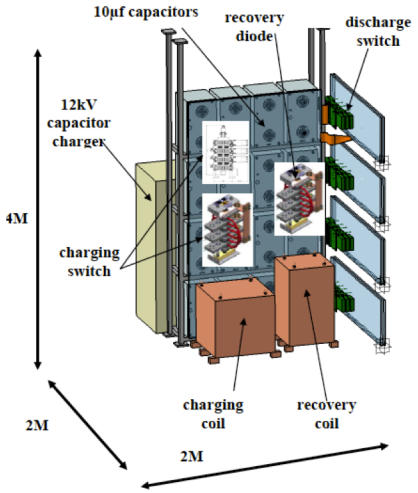
Power Supply for the target station







target inside the horn

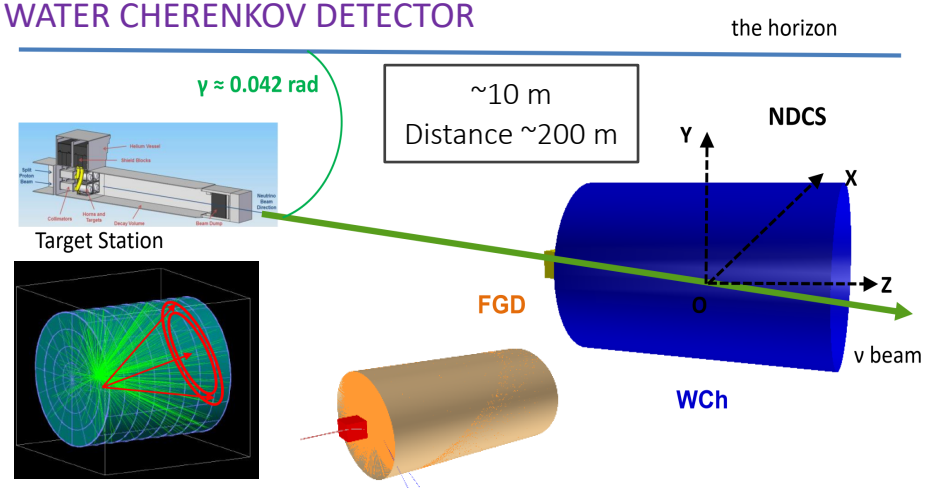


Work Package 5: Detectors

Objectives:

- Define performance of water Cherenkov detectors, including efficiency as a function of threshold and background evaluation, and cost estimate.
- Design for the near detector in order to measure the absolute flux normalisation, differential neutrino cross-sections, backgrounds to the far detector, and cost estimate.
- Location of the far underground detector and mining subcontracting.

NEAR DETECTOR: FINE GRAINED TRACKER IN (~1 TONNE) MAGNETIC FIELD + KTONNE MASS WATER CHERENKOV DETECTOR



Simulation principle:

- Neutrino beam produced by FLUKA on disk at 50, 250, 500 m
- Beam run through GENIE to create interaction vertices
- Particles emitted from vertex in GEANT 4
- Analysis of the emitted Cherenkov light

Work Package 5: Detectors

Objectives:

- Define performance of water Cherenkov detectors, including efficiency as a function of threshold and background evaluation, and cost estimate.
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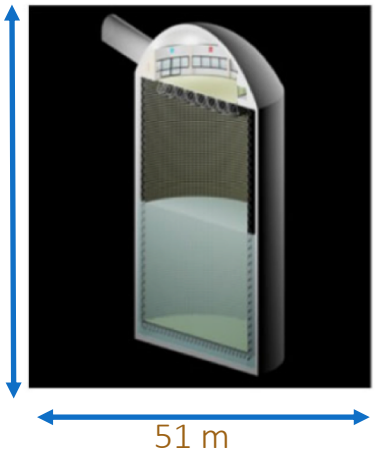
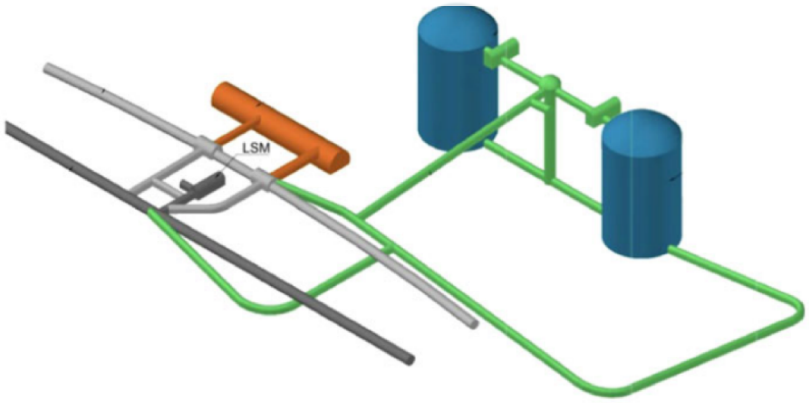
- Location of the far underground detector and mining subcontracting.

Phys. Rev. ST Accel. Beams 16, 061001 (2013)

Far Detector – Conceptual Design



MEMPHYS like Cherenkov detector (studied by LAGUNA and EUROv)

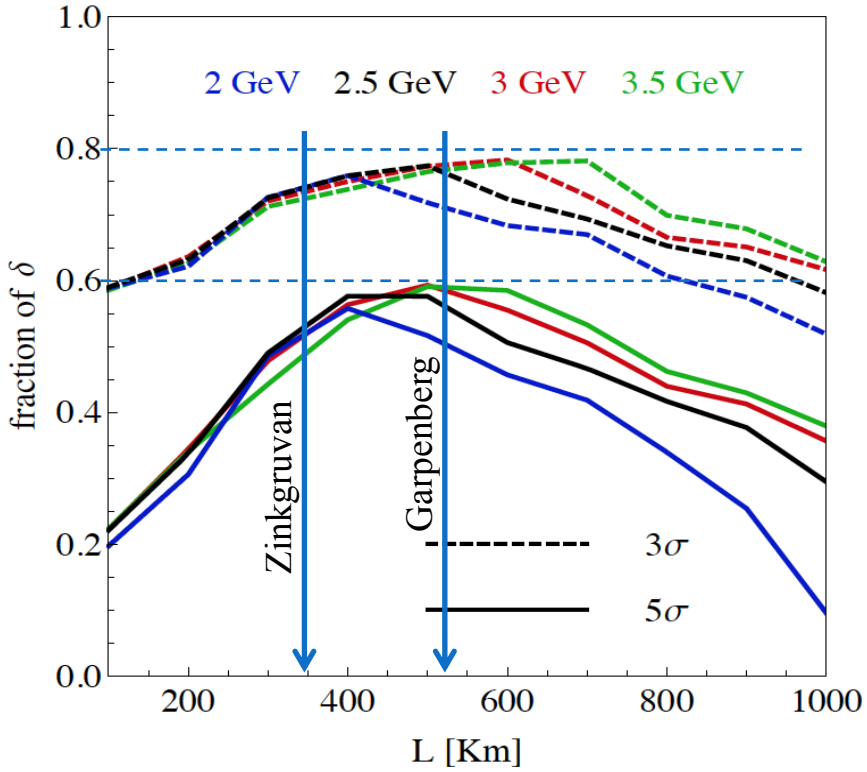


- 500 kt fiducial volume (~20xSuperK)
- Readout: ~240k 8” PMTs
- 30% optical coverage

Work Package 5: Detectors

At which distance to place the detector?

discovery potential of matter-antimatter asymmetry

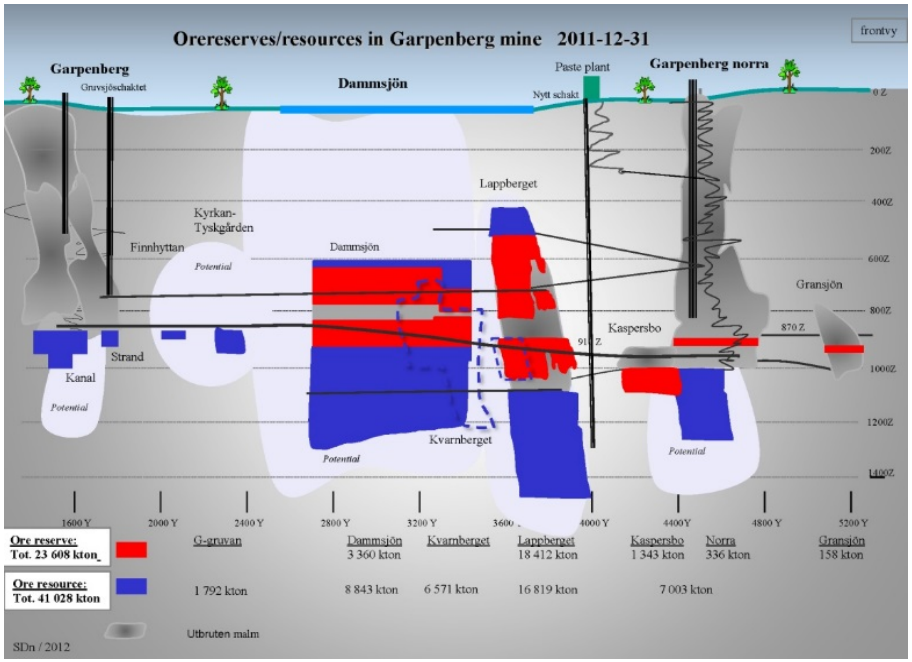


- ~60% δ_{CP} coverage at 5 σ C.L. Confidence level

Candidate active mines

Work Package 5: Detectors

- Distance from ESS Lund **540 km**
- Depth **1232 m**
- Truck **access tunnel**
- Hoist shaft free to use by ESSnuSB
- Rock-engineering prospection and studies in the Garpenberg-mine granite-zones



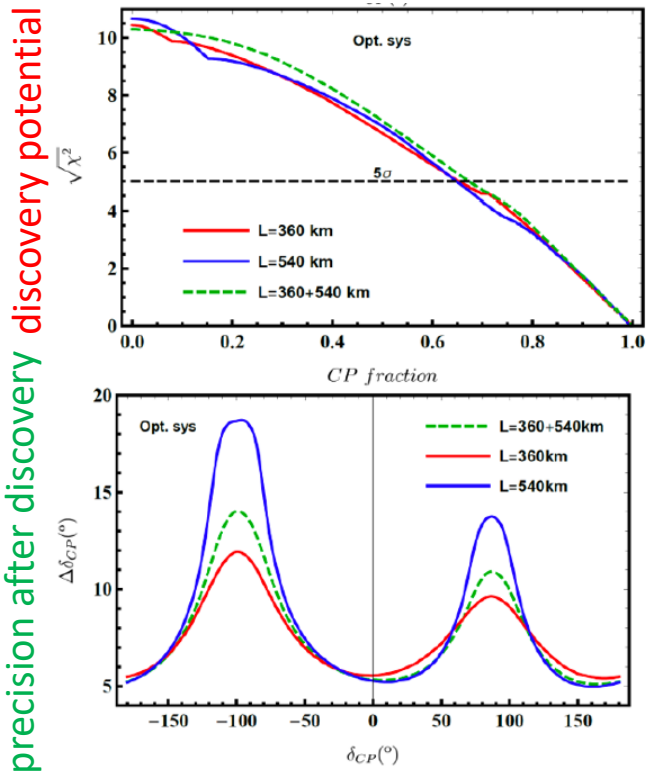
The owner of the Garpenberg mine, Boliden AB, has signed an MoU with Uppsala University, permitting agents of the University to access and make investigation in the Garpenberg mine.

The Garpenberg mine

Work Package 6: Physics

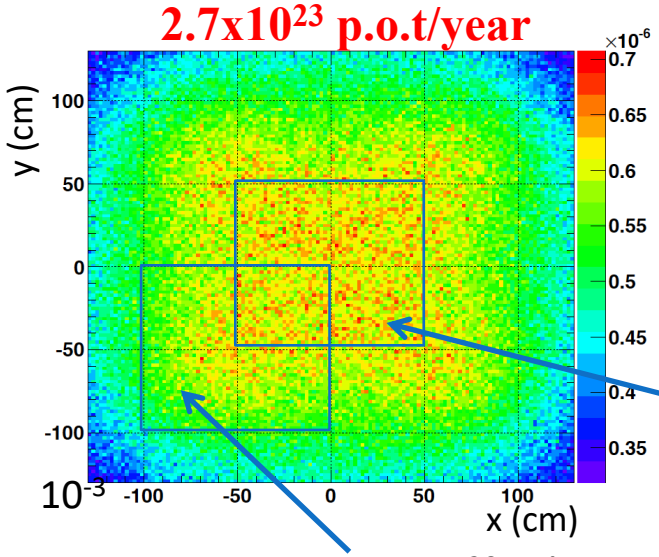
Objectives:

- Use the information provided by all WPs to determine the physics reach of the neutrino facility, taking into account the information successively provided from the other WPs and from currently functioning experiments as it become available.
- Compare the performance of this facility with those of other proposed facilities



Physics performance according to initial parameters

Muons at the level of the beam dump

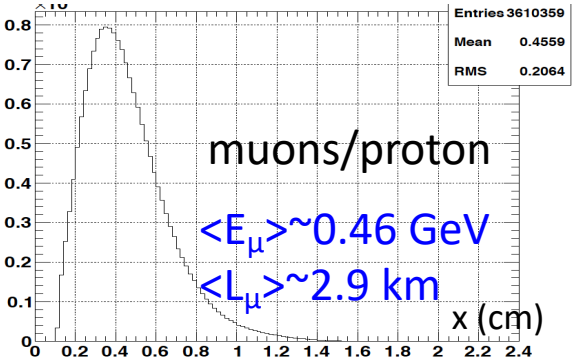


muons at the level of the beam dump (per proton)

more than 4x10^{20} μ/year from ESSS compared to 10^{14} μ used by all experiments up to now (10^{18} μ for COMET in the future).

4.2x10^{20} μ/year
(16.3x10^{20} for 4 m^2)

4.1x10^{20} μ/year



- input beam for future 6D m cooling experiments (for muon collider),
- good to measure neutrino x-sections (ν_μ, ν_e) around 200-300 MeV using a near detector,
- low energy nuSTORM,
- Neutrino Factory,
- Muon Collider

Muons synergies / workshop

« Prospects for Intensity Frontier Physics with Compressed Pulses from the ESS Linac » - Uppsala, Sweden, 2-3 March 2020

- To explore the possibilities of developing other Intensity Frontier experiments on or near the ESS site such as **nuSTORM, Neutrino Factory, Muon Collider, Coherent Neutrino Scattering** and **Decay at Rest,**
- **ESSmuSB?? -> C. Rubbia** "Further searches of the Higgs scalar sector at the ESS", 2019 arXiv:1908.05664v3[physics.acc-ph]

UPPSALA UNIVERSITET FREIA ESS NEUTRINO SUPER BEAM

-> Application to obtain an ERC Synergy Grant (R&D) / deadline nov 2020

https://indico.cern.ch/event/849674/page/19380

Possible ESSνSB schedule

(2nd generation neutrino Super Beam)

2012: inception of the project

Nucl. Phys. B 885 (2014) 127

2016-2019: beginning of COST Action EuroNuNet

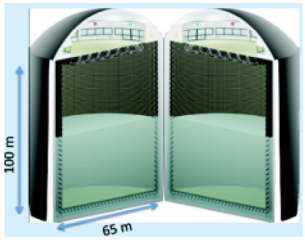
2018: beginning of ESSνSB Design Study (EU-H2020)

2021: End of ESSνSB Design Study, CDR and preliminary costing

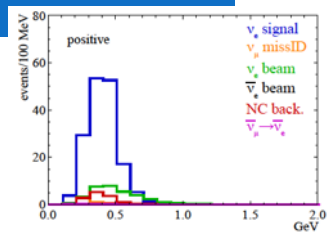
ESFRI

2022-2024: Preparatory Phase, TDR

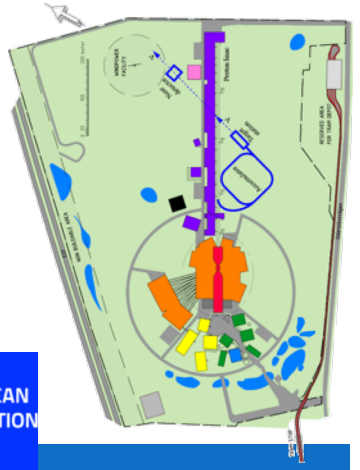
2025-2026: Preconstruction Phase, International Agreement



2027-2034: Construction of the facility and detectors, including commissioning



2035-: Data taking



EUROPEAN SPALLATION SOURCE

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Merci pour votre attention!

https://essnusb.eu/