ESS NEUTRINO SUPER BEAM

Funded by the Horizon 2020 Framework Programme of the European Union

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

The ESSnuSB project

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ESSnuSB

A design study for an experiment to measure CP violation at 2nd neutrino oscillation maximum.

CP violation in neutrino oscillations

Oscilation probability for neutrinos is different than oscillation probability for anti-neutrinos in vaccum.

probability of oscillation

$$P_{\alpha\to\beta} \neq P_{\overline{\alpha}\to\overline{\beta}}$$

neutrino flavour at production

neutrino flavour at detection

CP violation in ESSnuSB

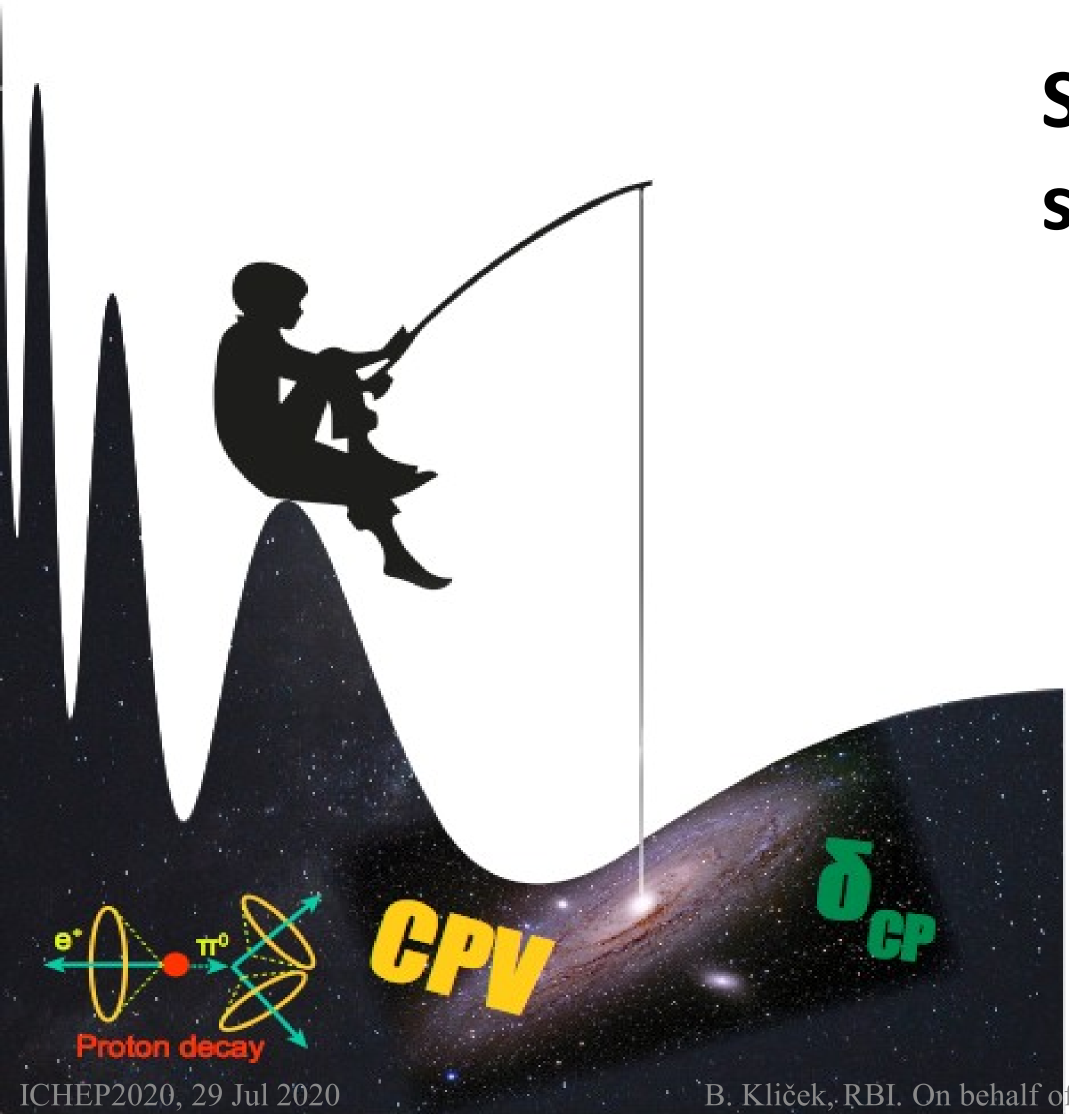
$$P_{\mu\rightarrow e} \neq P_{\overline{\mu}\rightarrow\overline{e}}$$

We will study ν_e and $\overline{\nu}_e$ appearance in ν_μ and $\overline{\nu}_\mu$ beam, respectively

The plan:

1. Run with ν_μ and look at ν_e appearance, then
2. Run with $\overline{\nu}_\mu$ and look at $\overline{\nu}_e$ appearance

Why 2nd maximum?



Statistics vs. systematics

Why 2nd maximum?
(hand waving approach)

The good

$$\frac{(P_{\mu\to e} - P_{\bar{\mu}\to\bar{e}}) \text{ @ 2nd osc. max.}}{(P_{\mu\to e} - P_{\bar{\mu}\to\bar{e}}) \text{ @ 1st osc. max.}} \sim 3$$

In vaccum, this ratio depends only on neutrino mass square differences

The bad

You get less statistics because you have to either:

- Move 3x further than 1st maximum - flux 9x smaller
- Reduce energy 3x – cross-section at least 3x smaller

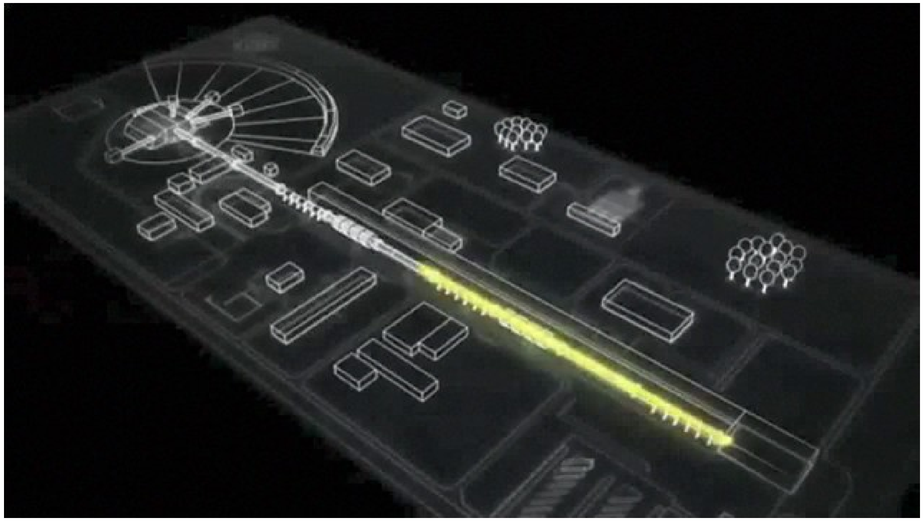
The optimal

- Depends on the systematic error – assume similar at 1st and 2nd oscillation maximum
- 3x signal at 2nd osc. maximum is less obscured by systematics, but we have less statistics (measured appearance events).
  - If the signal at 2nd maximum is not obscured by larger statistical error, then 2nd maximum is better.
  - Intense beam helps here, as does having larger θ_{13} because $P_{\mu\to e}$ and $P_{\bar{\mu}\to\bar{e}}$ are larger and we get more events.
- With 0 systematic error, first maximum is better
  - more statistics, even though the effect is smaller.

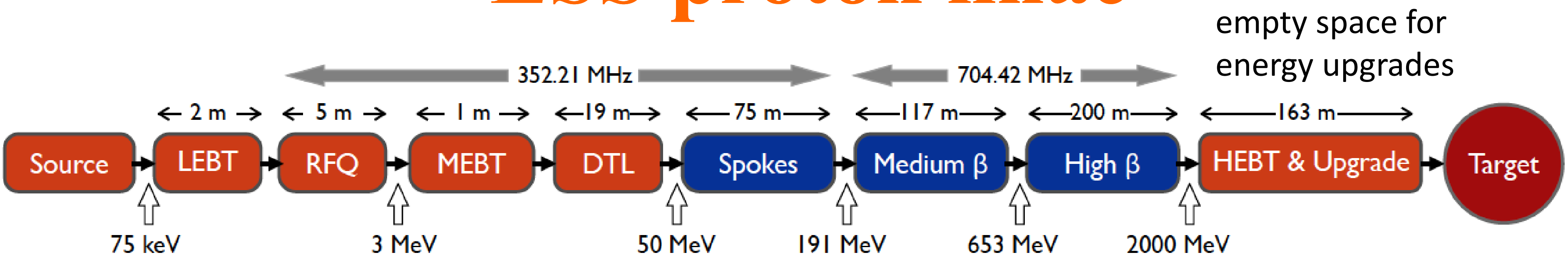
2nd maximum?

As it happens, a very intense proton linac is in construction near Lund, Sweden.

And θ_{13} is large enough.

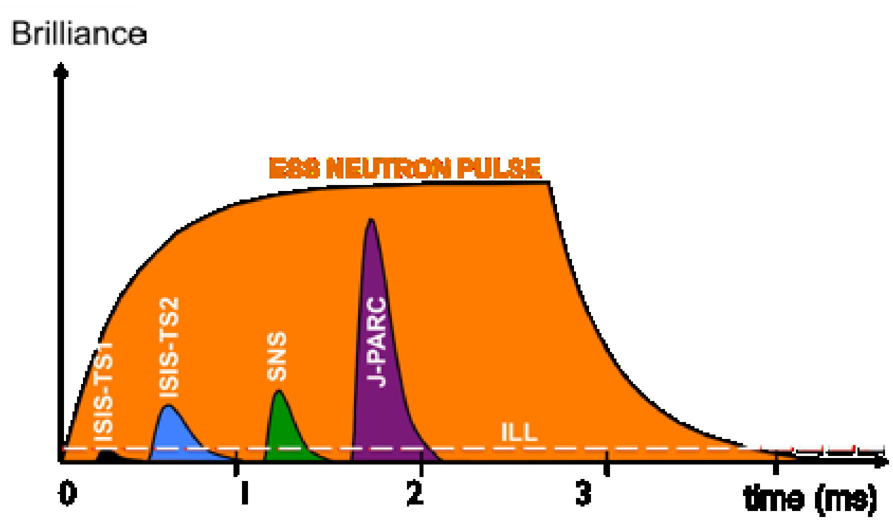


ESS proton linac



- The ESS will be a copious source of spallation neutrons.
- 5 MW average beam power.
- 125 MW peak power.
- 14 Hz repetition rate (2.86 ms pulse duration, 10^{15} protons).
- Duty cycle 4%.
- 2.0 GeV kinetic energy protons
  - up to 3.5 GeV with linac upgrades
- **>2.7x10^{23} p.o.t/year.**

450 mg of protons/year at 95% speed of light!

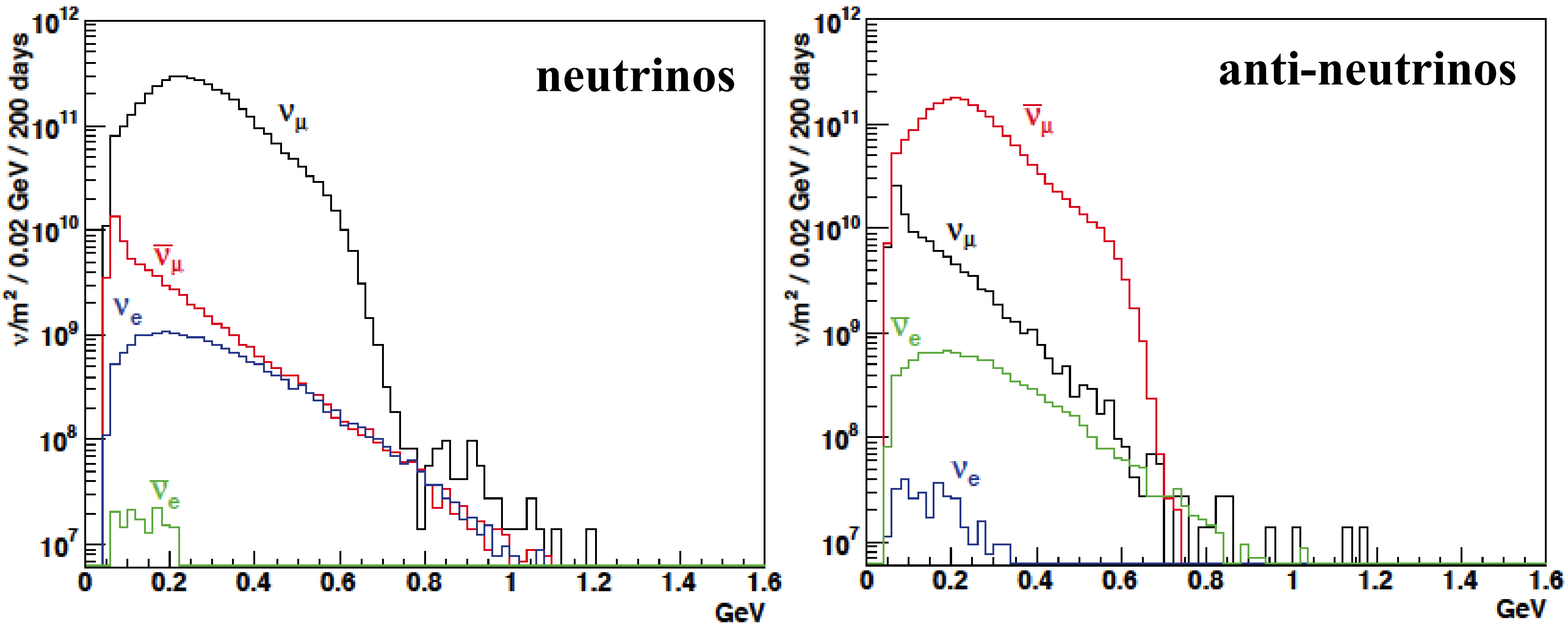


First operation of the linac in 2023.

Modifications to ESS linac to produce neutrinos

- Neutrino optimised target station
- Underground near detector hall
- Increase proton energy to 2.5 GeV kinetic
- Double the linac rate the rate (14 Hz → 28 Hz), from 4% duty cycle to 8%.
- ESS proton pulse is too long – accummulator ring (C~400 m) needed to compress 2.86 ms proton pulses to ~ 1.3 μs, otherwise:
  - magnetic horns would melt
  - atmospheric neutrino background would be too large for CP violation measurement
- The neutron program must not be affected and if possible synergetic modifications.

ESSνSB ν energy distribution (without optimisation)



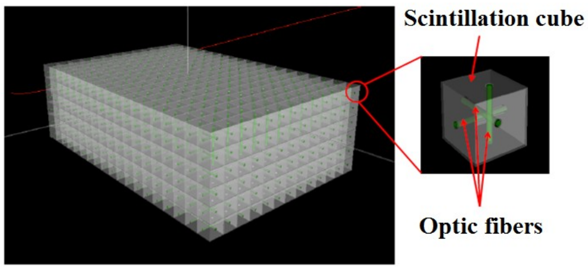
- almost pure ν_μ beam
- small ν_e contamination which could be used to measure ν_e cross-sections in a near detector

	positive		negative	
	$N_\nu\ (\times 10^{10})/\mathrm{m}^2$	%	$N_\nu\ (\times 10^{10})/\mathrm{m}^2$	%
ν_μ	396	97.9	11	1.6
$\bar{\nu}_\mu$	6.6	1.6	206	94.5
ν_e	1.9	0.5	0.04	0.01
$\bar{\nu}_e$	0.02	0.005	1.1	0.5

at 100 km from the target and per year (in absence of oscillations)

(Nucl. Phys. B 885 (2014) 127)

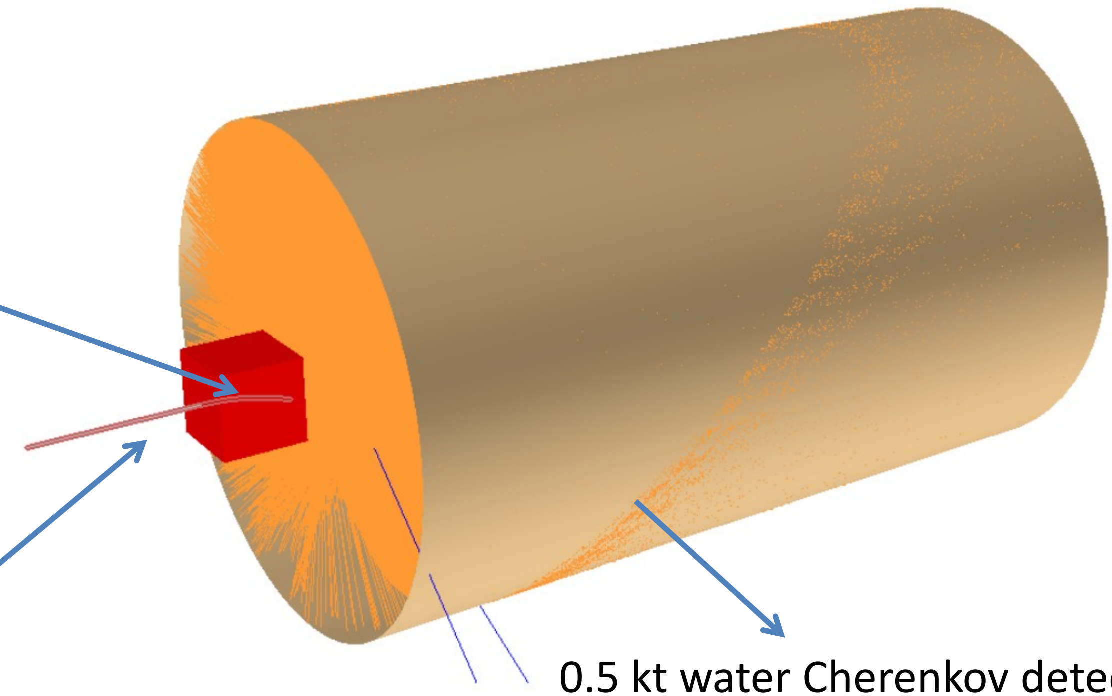
Near Detectors



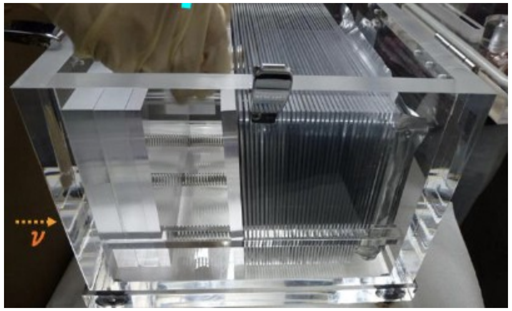
Super-FGD like detector
- 1 – 4 t target mass

Beam

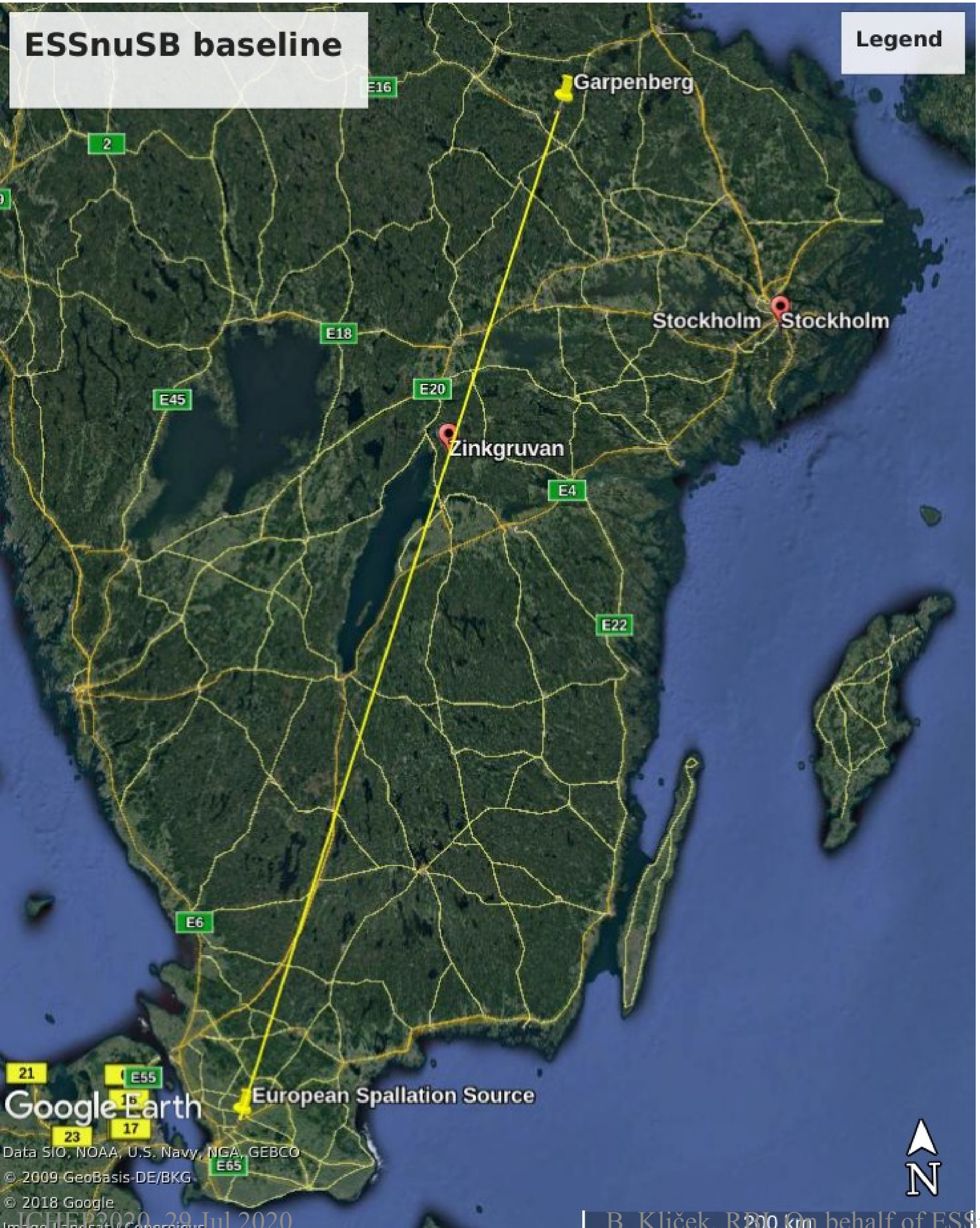
?



0.5 kt water Cherenkov detector



Possible addition:
NINJA-like water-emulsion detector



Far detector position

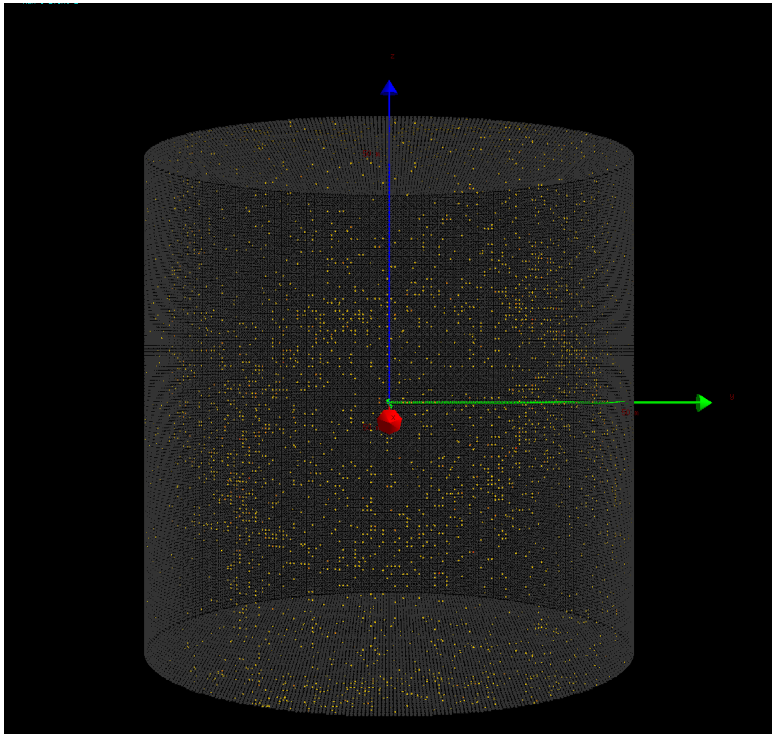
Baseline:

- Garpenberg mine, 540 km from the neutrino source, corresponding to 2nd oscillation maximum.

Alternatives:

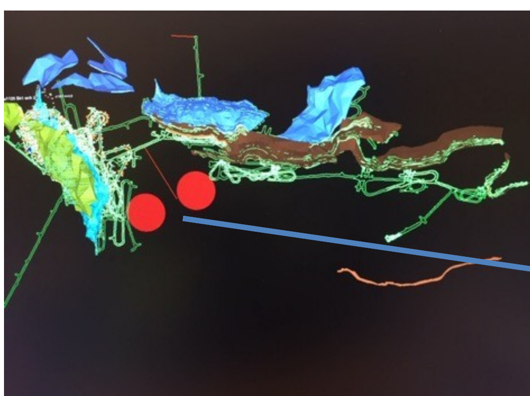
- Zinkgruvan mine, 340 km from source
- Garpenberg and Zinkgruvan, 250 kt each

Far detectors



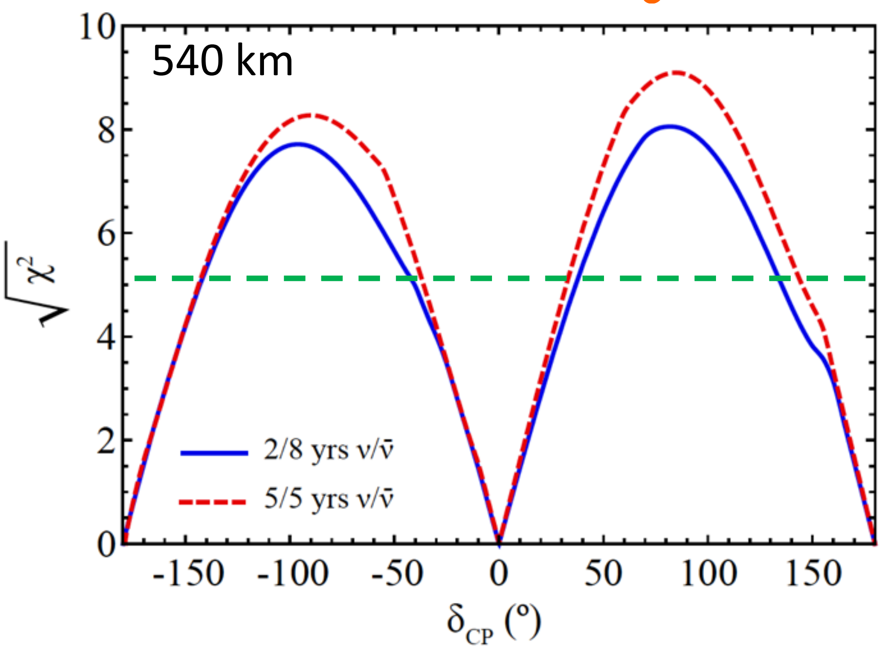
Baseline
- 2 x 270 kt fiducial volume (~20xSuperK)
- Readout: 2 x 38k 20” PMTs
- 30% optical coverage

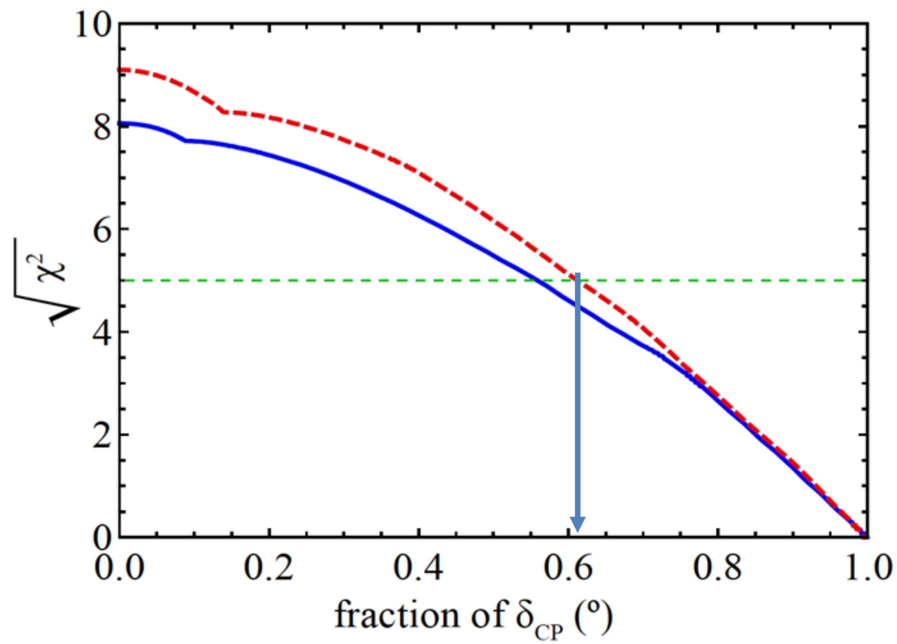
Can also be used for other purposes:
- Proton decay
- Astroparticles
- Galactic SN ν
- Supernovae "relics"
- Solar Neutrinos
- Atmospheric Neutrinos



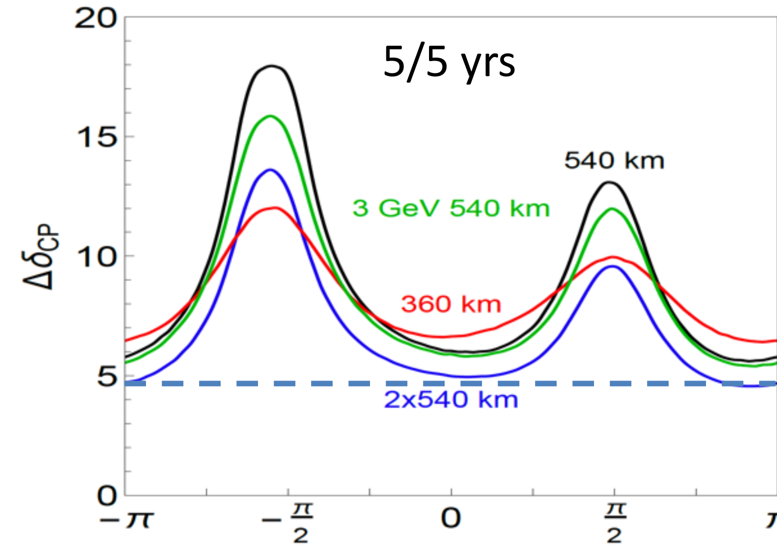
Possible positions at Zinkgruvan mine

Physics Performance



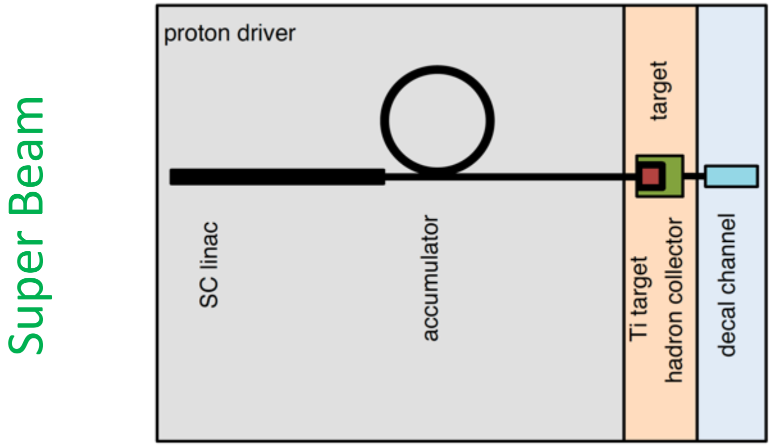


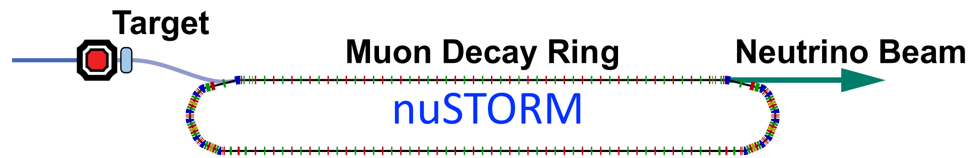
- little dependence on mass hierarchy,
- δ_{CP} coverage at 5 σ C.L. up to **60%**,
- δ_{CP} accuracy down to **6°** at 0° and 180° (absence of CPV for these two values),
- not yet optimised facility,
- **5/10%** systematic errors on signal/background.



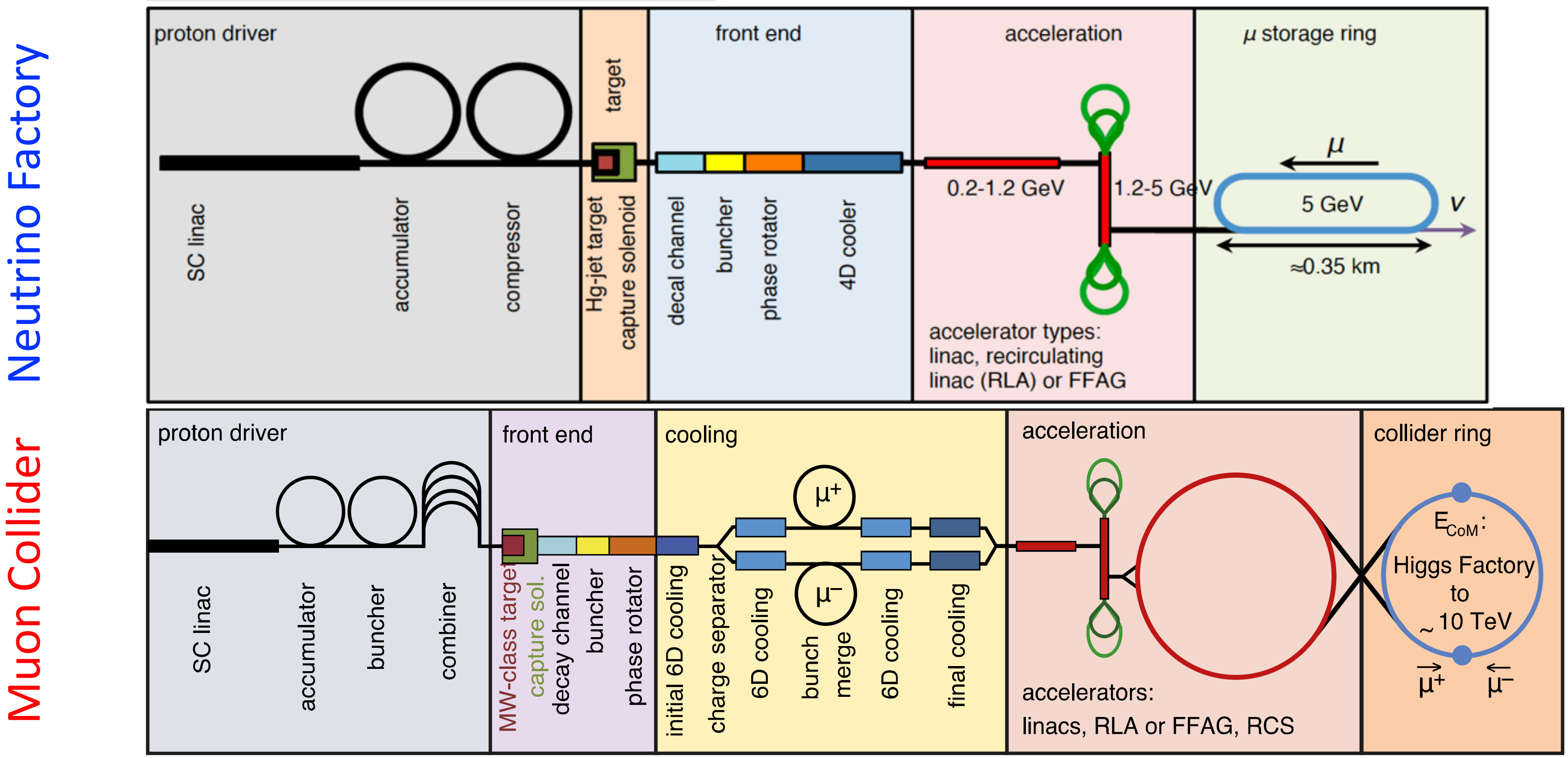
ESSvSB and (R&D) synergies

Dedicated series of workshops is organized
https://indico.cern.ch/event/849674/





+Decay At Rest and Coherent scat.
(with short pulses)



EuroNuNet

- **COST application 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**)
  - **Major goals of EuroNuNet**:
    - to aggregate the community of neutrino physics in Europe to study a neutrino long baseline concept in a spirit of inclusiveness,
    - to impact the priority list of High Energy Physics policy makers and of funding agencies to this new approach to the experimental discovery and precision measurement of leptonic CP violation.
    - 13 participating countries

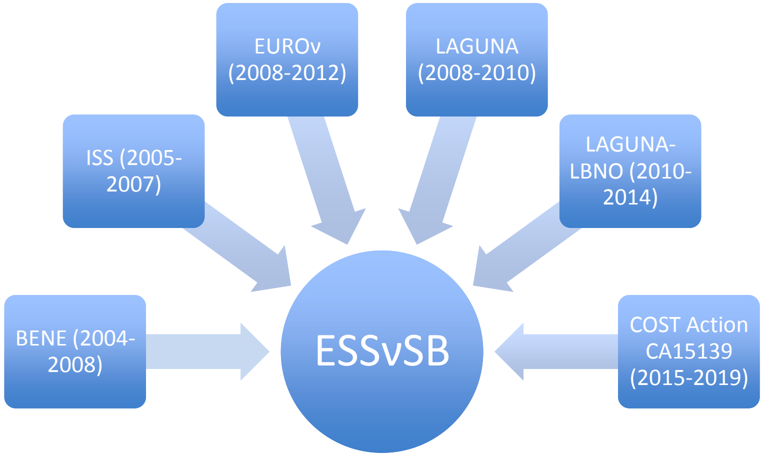
FINISHED

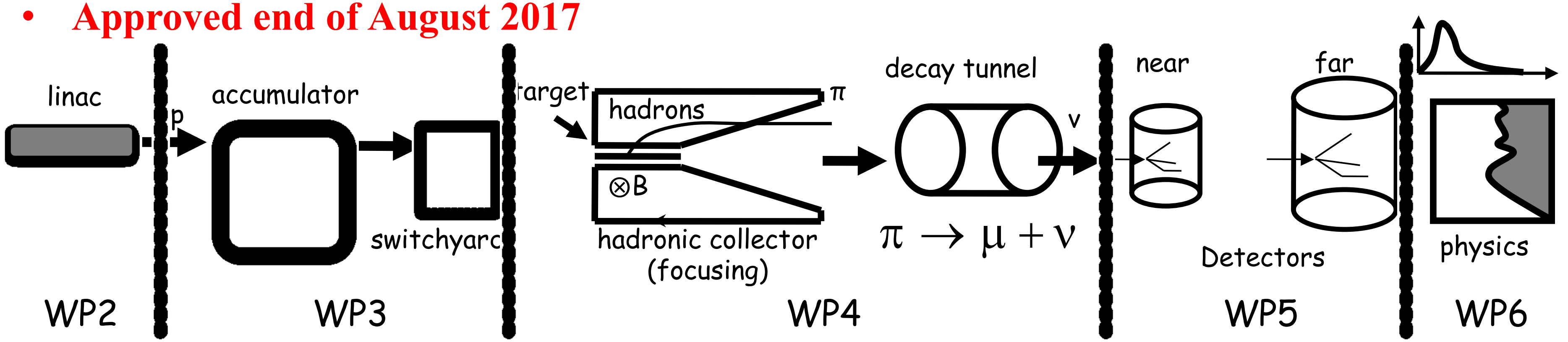
The members are countries which signed the Action MoU

http://euronunet.in2p3.fr/

ESSνSB at the European level

- A **H2020** EU **Design Study** (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€**
  - **15 participating institutes from 11 European countries including CERN and ESS**
  - 6 Work Packages
  - **Approved end of August 2017**





Possible ESSνSB schedule

(2nd generation neutrino Super Beam)

ESS NEUTRINO SUPER BEAM

COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

2012: inception of the project

2016-2020: COST Action EuroNuNet

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

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

ESFRI

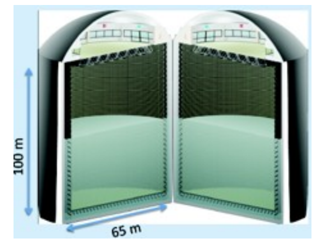
2022-2024: Preparatory Phase, TDR

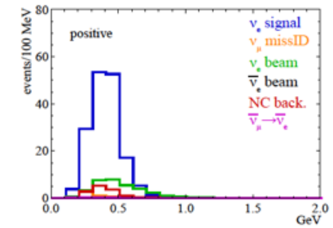
2025-2026: Preconstruction Phase, International Agreement

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

2035-: Data taking

Nucl. Phys. B 885 (2014) 127





EUROPEAN SPALLATION SOURCE

Conclusions

- **ESSnuSB** aims to observe CP violation in neutrino oscillations at the 2nd oscillation maximum using 500 kt WC detector
  - 5 σ could be reached over 60% of δ_{CP} range
- **ESS linac** will be most powerful proton accelerator in the world
  - can be used to generate intense neutrino beam to go to 2nd maximum
  - will start operation by 2023, decision on neutrino programme pending
  - proposed modifications would allow a **rich additional physics** programme at ESS
    - muon physics, DAR experiments, short neutron pulses, ...
- **Large far detectors** can also be used for rich astroparticle physics programme
- **COST** network project **CA15139** and the **ESSnuSB EU-H2020** Design Study support this project

The end