

Particle Physics at the European Spallation Source



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Stockholm University

The European Spallation Source

World's brightest neutron source.

Multidisciplinary research centre with 17 European nations participating.

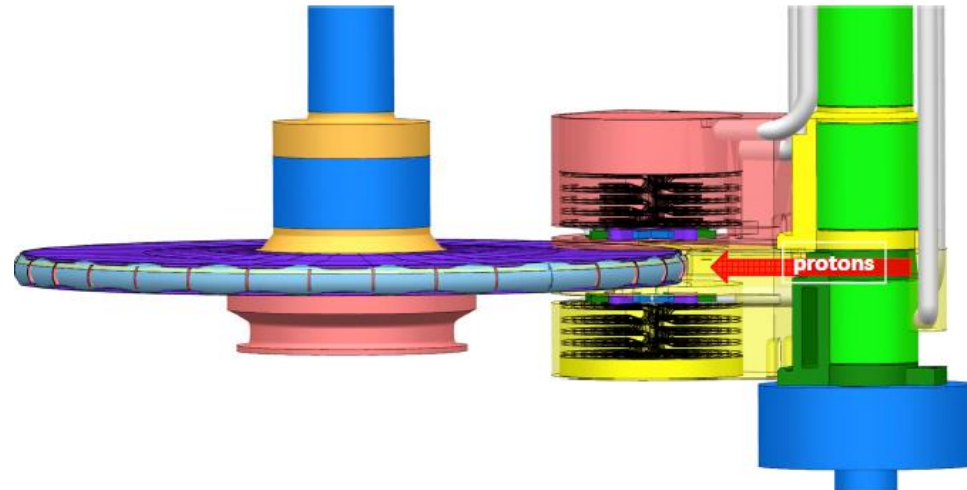
Lund.

Start operations in 2027/2028.

Up to 2 GeV protons (3ms long pulse, 14 Hz) hit rotating tungsten target.

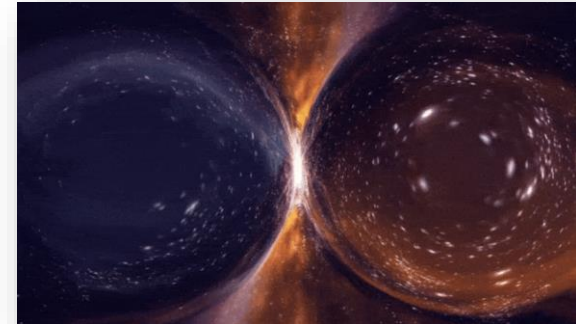
Cold neutrons after interaction with moderators.

15 beamlines/instruments – none are Swedish-led



The ESS Fundamental Physics Program

- The ESS will be the brightest neutron source in the world enabling new opportunities for many different scientific fields, including materials and life sciences, energy, environmental technology, cultural heritage and **fundamental physics**
- The ESS will have the unprecedented capability to access and **unlock some of the greatest challenges of the universe**
- We are developing a broad fundamental physics program, that will be evaluated in few years, with a time span of at least two decades
- This includes mainly
 - Physics with neutrons
 - Physics with neutrinos
- The ESS sensitivity is orthogonal and complementary to the collider program

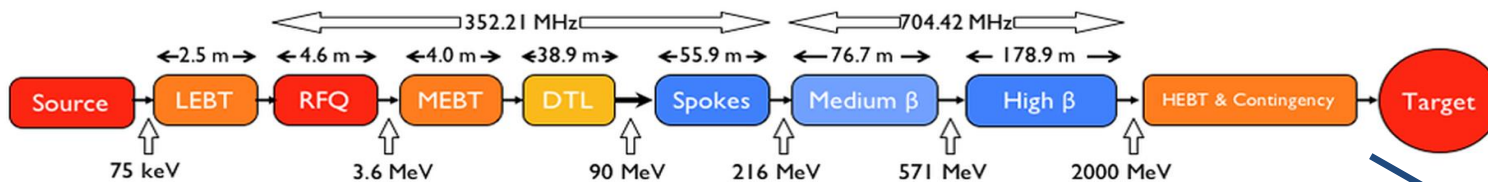


ESSnuSB

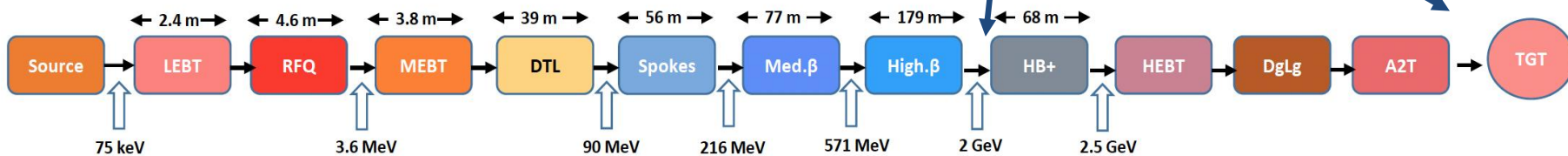


- Leptonic CP violation at the 2nd maximum of $\nu_\mu \rightarrow \nu_e$ Neutrino beam produced by upgraded ESS linac at 10MW
- 20 participating institutes/organisations from 11 countries.
- H2020-funded CDR (Eur. Phys. J. Spec. Top. 2022,. 231)
- ESSnuSB+ (Horizon) is a continuation of this study which focuses on neutrino interaction cross-section measurement at the low neutrino energy region

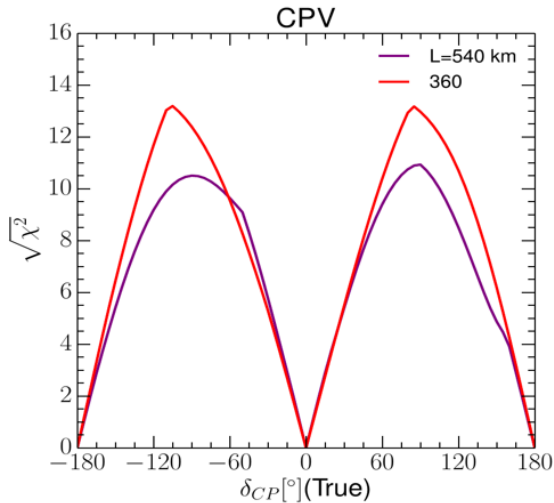
ESS Accelerator design at 2GeV and 5MW power on target



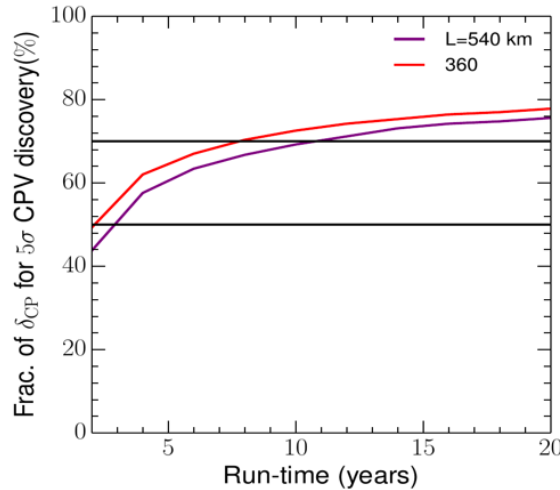
ESS Accelerator could be upgraded to 10MW



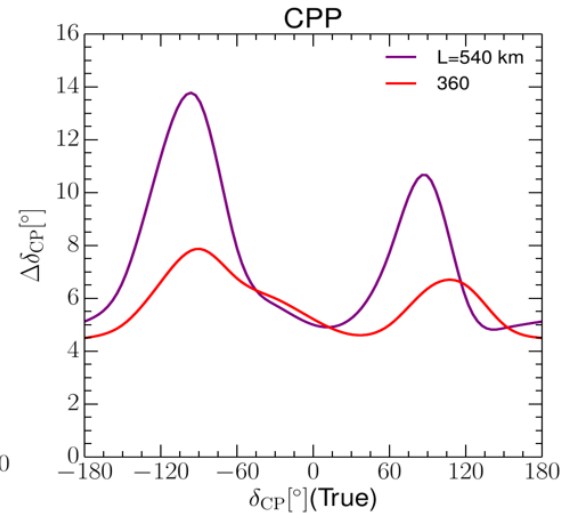
ESSnuSB and ESSnuSB+



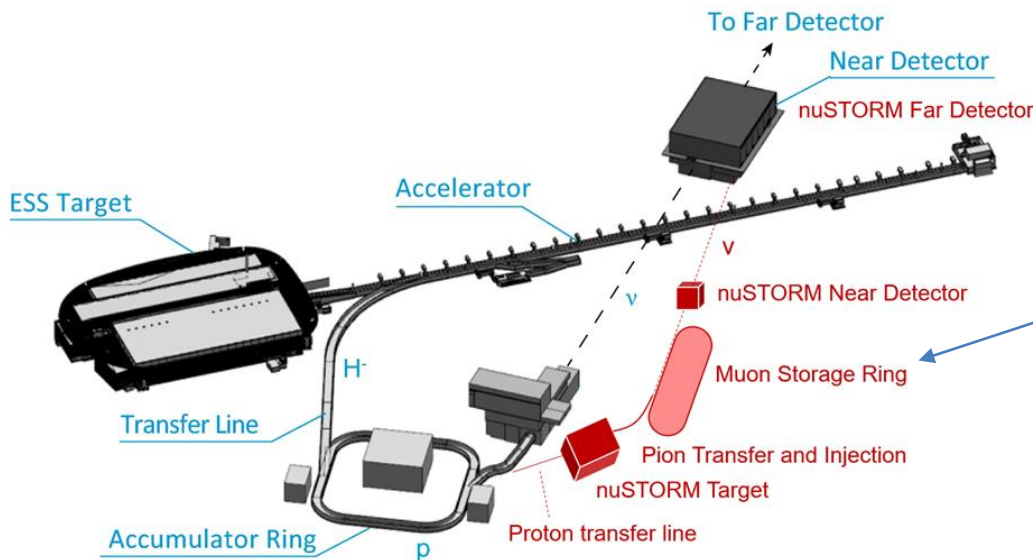
Sensitivity for $\delta_{CP} = \pm \pi/2$:
 11 σ (540 km)
 13 σ (360 km)



70% δ_{CP} coverage @ 5 σ :
 11 years (540 km)
 8 years (360 km)



High precision of δ_{CP} measurement



NuSTORM: Muons from pion decay stored in racetrack ring

ν from muon decay for neutrino interaction measurements and sterile neutrino searches

The Large Beam Port

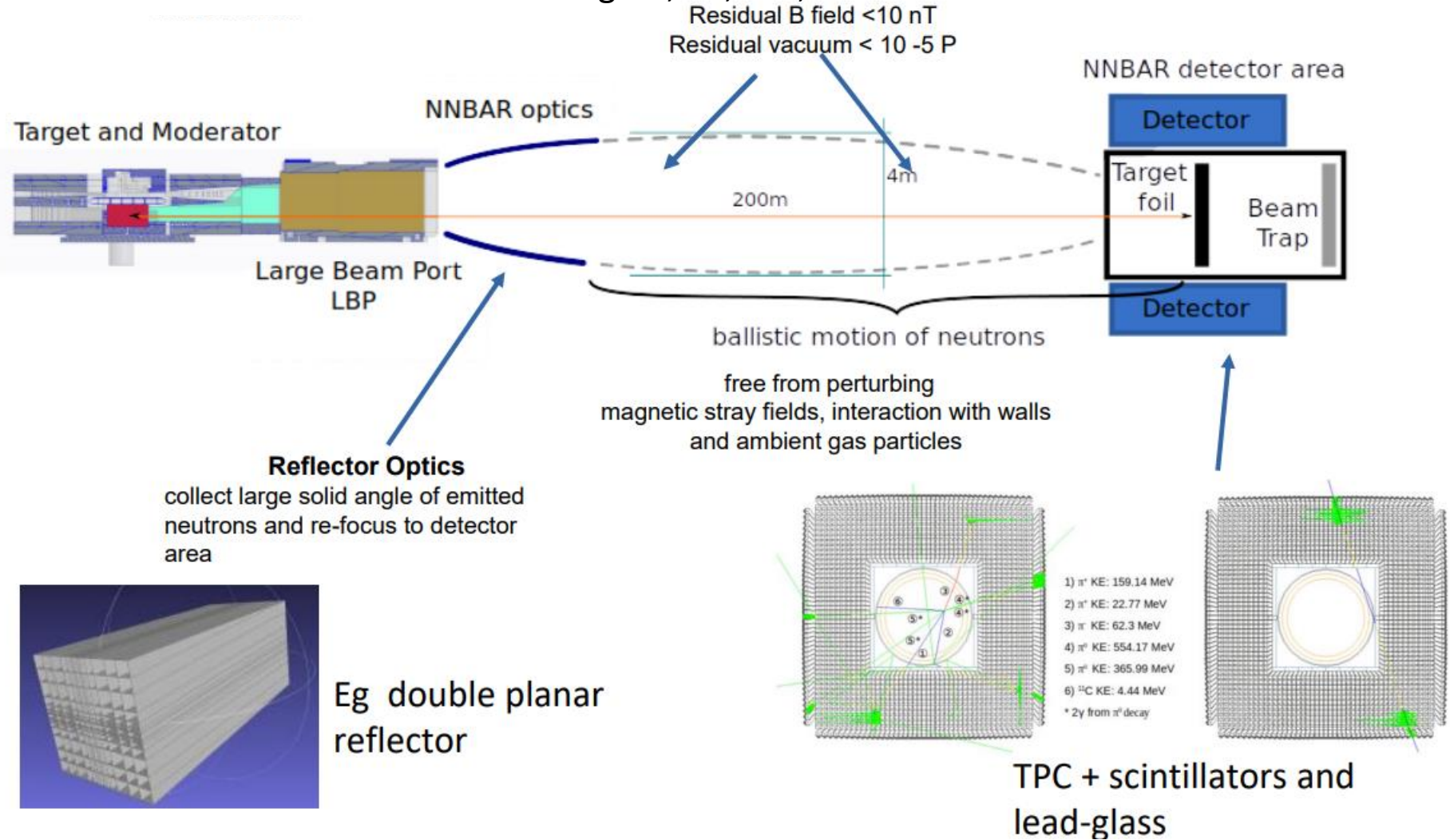


- It is able to deliver 1.5×10^{15} n/s there is no beamline currently available or planned at any other facility that could reach a flux even close to this number
- Enables $n \rightarrow \bar{n}$ search with three orders of magnitude improvement in sensitivity
- Ultra-cold and very cold neutron sources that can be exploited for e.g. neutron electric dipole moment.
- CDR for LD lower moderator and LBP exploitation from 3MEuro HighNESS (H2020) program

HIBEAM/NNBAR

NNBAR – search for neutron-antineutron.

13 institutes from 7 countries including SU,UU,CTU,LU



10³ increase in discovery potential compared to previous experiment

H2020-funded CDR : *J.Neutron Res.* 25 (2024) 3-4, 315-406

HIBEAM - multi-purpose magnetically controlled beamline for fundamental physics

Neutron conversions

$$\hat{H} = \begin{pmatrix} m_n + \vec{\mu}_n \vec{B} & \varepsilon_{n\bar{n}} & \alpha_{nn'} & \alpha_{n\bar{n}'} \\ \varepsilon_{n\bar{n}} & m_n - \vec{\mu}_n \vec{B} & \alpha_{n\bar{n}'} & \alpha_{nn'} \\ \alpha_{nn'} & \alpha_{n\bar{n}'} & m_{n'} + \vec{\mu}_{n'} \vec{B}' & \varepsilon_{n'\bar{n}'} \\ \alpha_{n\bar{n}'} & \alpha_{nn'} & \varepsilon_{n'\bar{n}'} & m_{n'} - \vec{\mu}_{n'} \vec{B}' \end{pmatrix}$$

Neutron – antineutron/sterile neutrons

Bespoke annihilation detector or WASA (Csl) crystal calorimeter co-owned by UU.

Detector prototypes

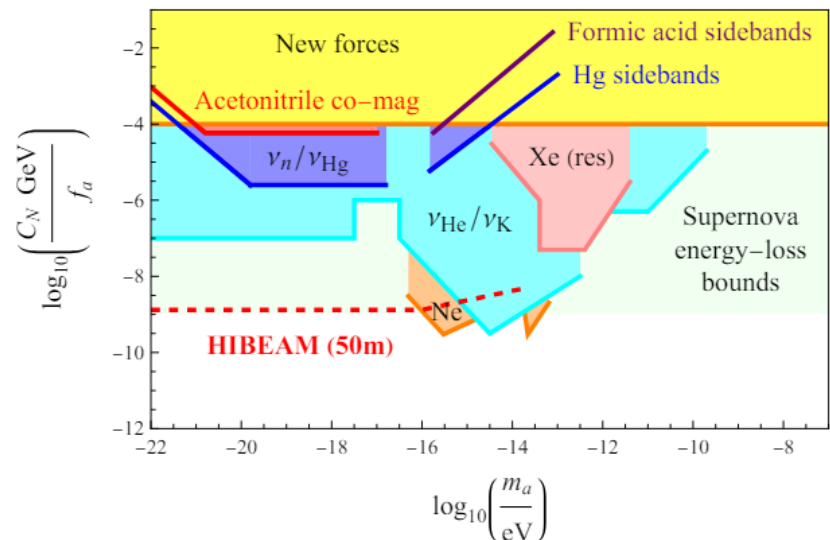
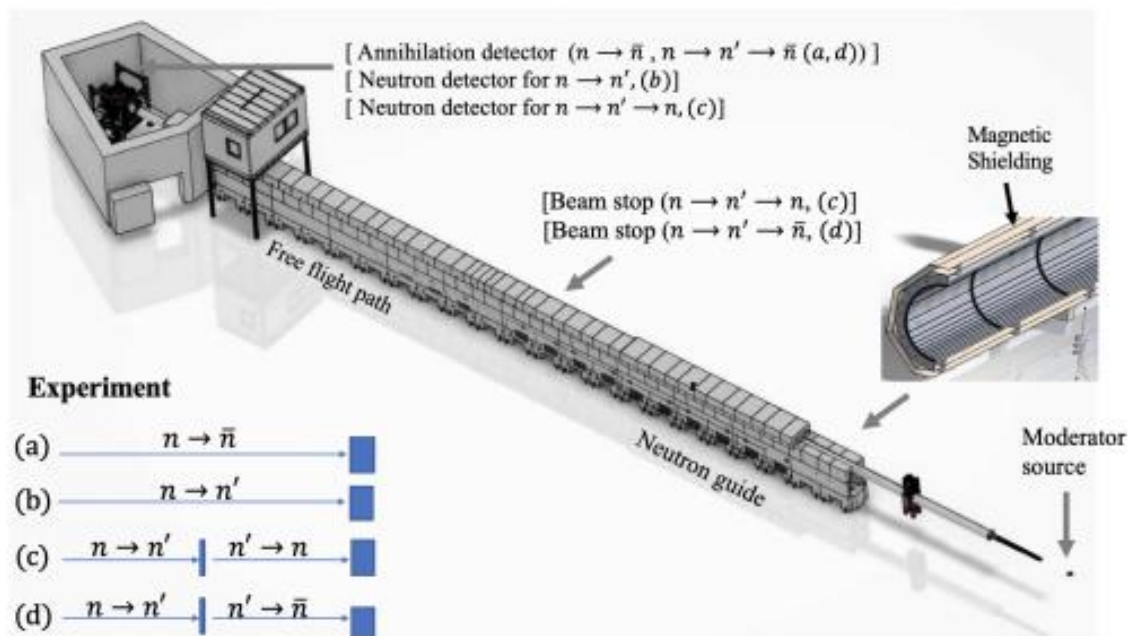
Can exceed last experiment by factor 10

Ultra-low mass Axions

Most sensitive lab-based experiment (PRL).

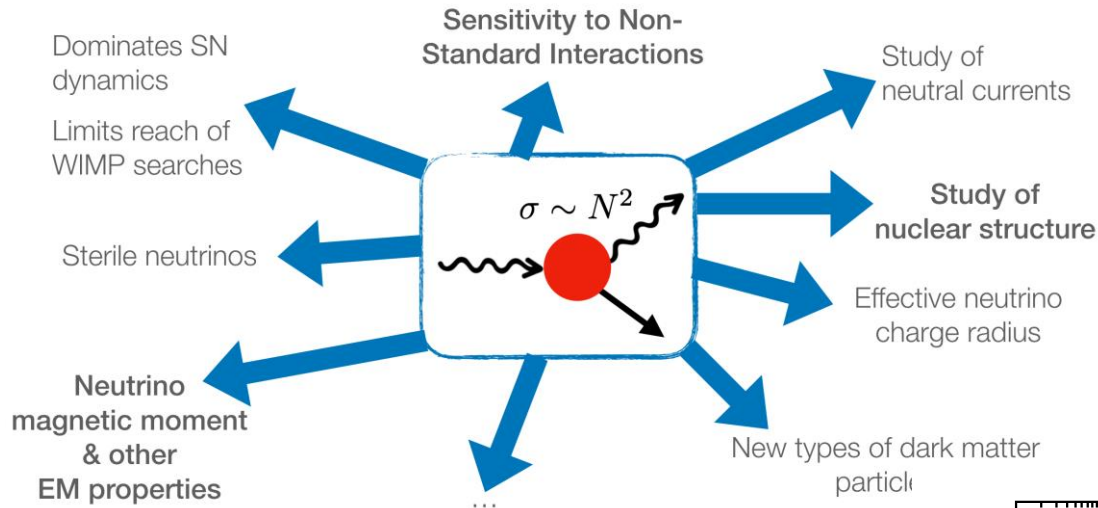
VR-RFI + VR-Project + SFRF+STINT+Olle Engkvist, Craaford.

Design report in preparation.

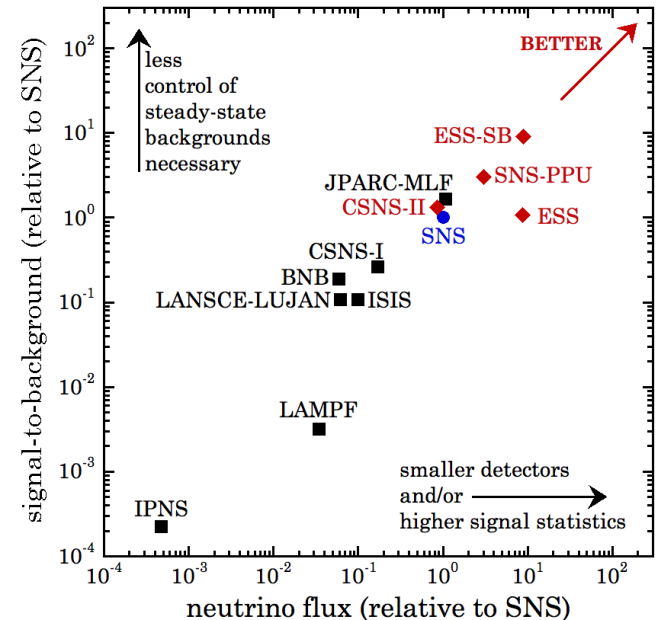


Coherent Elastic Neutrino-Nucleus Scattering (CE ν NS)

Neutrinos scatter on a nucleus which acts as a single particle



Experimental challenge of kEV energy loss
Broad sensitivity increase with ESS.



Swedish Consortium for Fundamental Physics at the ESS

Coordinate and support the particle physics proposals being made by physicists in Sweden for projects to be carried out in collaboration with international colleagues at the ESS. Additionally, it was proposed that the consortium should organize yearly workshops on the progress of these projects in Sweden and promote education and outreach activities.

Constituted during the RECFA meeting in Lund 16 May 2023.

Open for all interested persons to join.

Valentina Santoro is the current chair of the Consortium Executive Group

Experimentalists and theorists from UU, LU, SU, KTH, CTU, LTU

Workshop in Spring 2025.

Summary

- The ESS will open a unique discovery window at the intensity frontier
- Capabilities addressing key open questions with a variety of experiments.
- Swedish community is coming together.