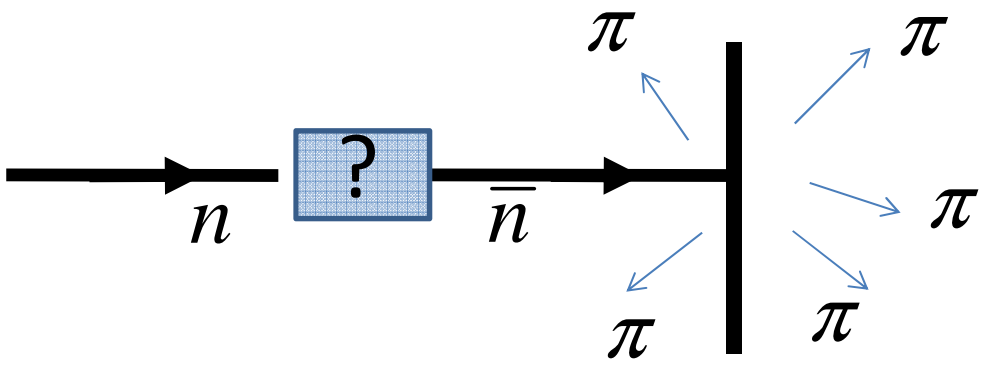
A search for free $n \rightarrow \overline{n}$ oscillations at the ESS



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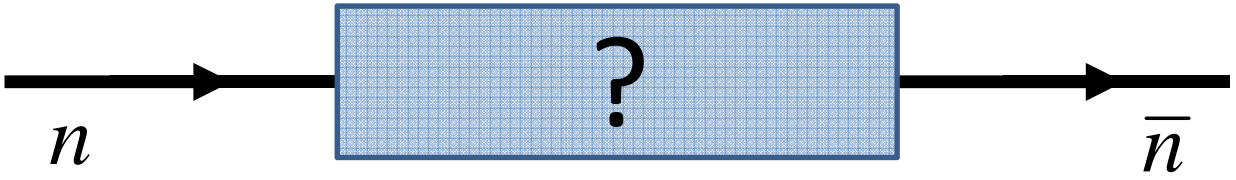
Motivation for a search for $n\bar{n}$

- Why baryon number violation ?
  - Baryon number is not a ”sacred” quantum number
  - ”Accidental” symmetry in the SM
  - BNV in SM by non-perturbative processes (instantons)
  - Generic BNV in BSM theories
- Why $n\bar{n}$?
  - Baryogenesis: $n\bar{n}$ is BNV and CP-violating (Sakharov conditions)
  - Synergy between $n\bar{n}$ $(\Delta B=2)$ and double neutrinoless β–decay $(\Delta L=2)$ via $B\text{-}L$
  - Scan for BNV beyond LHC energies up to ~GUT scale.
  - Set limit on stability of matter
  - Few pure BNV searches
    - Nucleon decay searches largely require BNV and LNV
    - $n\bar{n}$ and dinucleon decays sensitive to BNV -only

See arXiv:1410.1100 for more details

$n \rightarrow \bar{n}$ mixing formalism



$$i\hbar \frac{\partial}{\partial t}\begin{pmatrix} n \\ \bar{n} \end{pmatrix} = \begin{pmatrix} E_n & \delta m \\ \delta m & E_{\bar{n}} \end{pmatrix}\begin{pmatrix} n \\ \bar{n} \end{pmatrix}$$

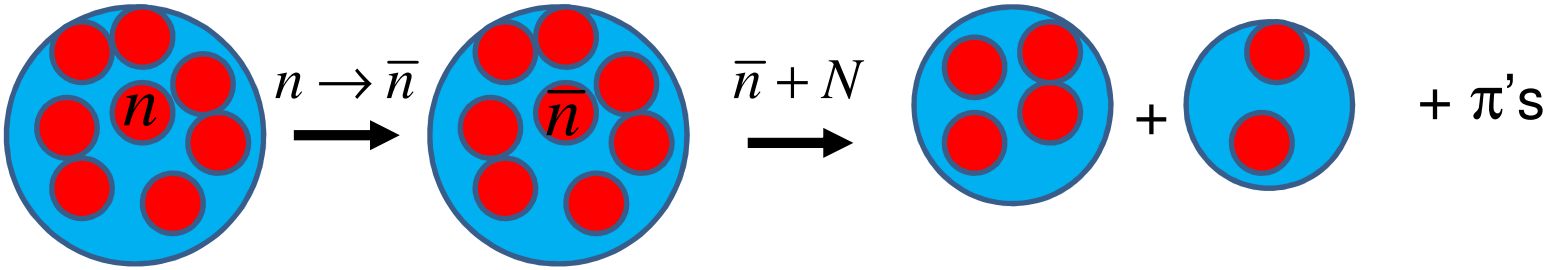
$\delta m = \langle \bar{n} | H_{eff} | n \rangle < 10^{-29}$ MeV $= n\bar{n}$ mixing physics

$$P_{n\rightarrow\bar{n}} = \left(\frac{\delta m}{\Delta E}\right)^2 \sin^2(\Delta E \times t)$$

$\Delta E =$ energy difference of n and $\bar{n}$

Search strategies and limits

Nuclear disintegration after neutron oscillation



$P_{n\to\bar{n}} = \left(\frac{\delta m}{\Delta E}\right)^2 \sin^2(\Delta E \times t)$, $\Delta E \sim 100$ MeV . Suppression: $\left(\frac{\delta m}{\Delta E}\right)^2 < 10^{-60}$

Best current limits (SuperKamiokande) $\Rightarrow$ $\tau_{free} > 2.7\times10^8$ s

Free neutron oscillation

$$\Delta E \times t \ll 1 \Rightarrow P_{n\to\bar{n}} \sim (\delta m \times t)^2 = \left(\frac{t}{\tau_{free}}\right)^2$$

Best current limit (ILL) $\tau_{free} > 0.87\times10^8$ s

Free neutron oscillation at ESS

$\sim 10^3$ increase in $P_{n\to\bar{n}}$ sensitivity: $\tau_{free} > 3\times10^9$ s

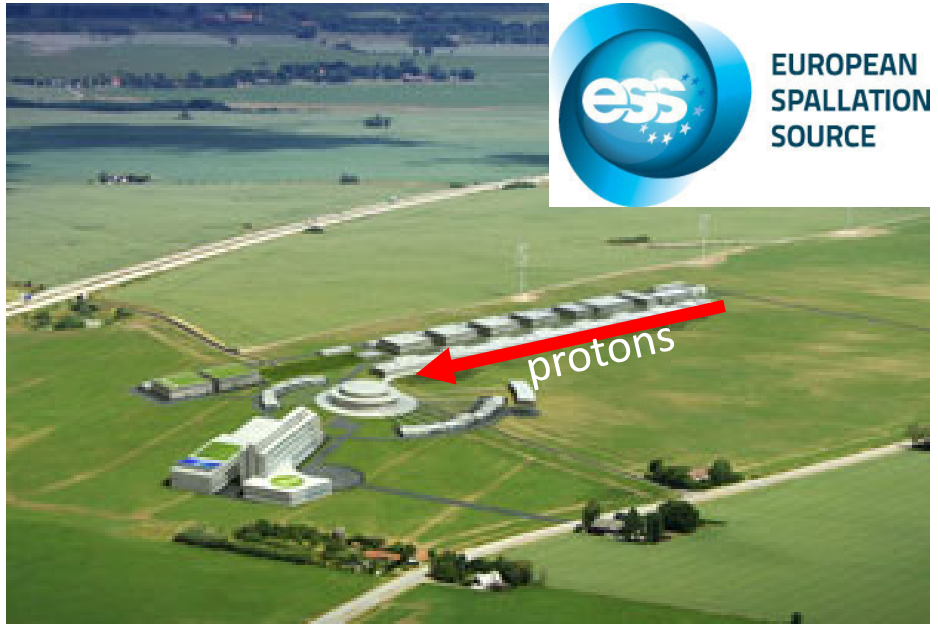
Stability of matter sensitivity up to $\sim 10^{34}$ years.

The European Spallation Source

High intensity spallation neutron source

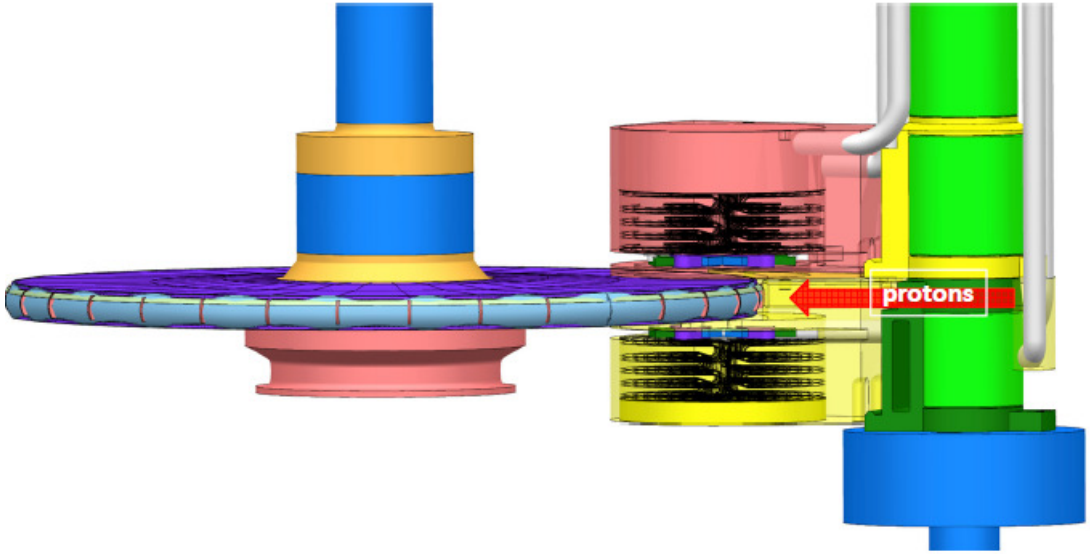
Multidisplinary research centre with 17 European nations participating.

Lund, Sweden.
Start operations in 2019.

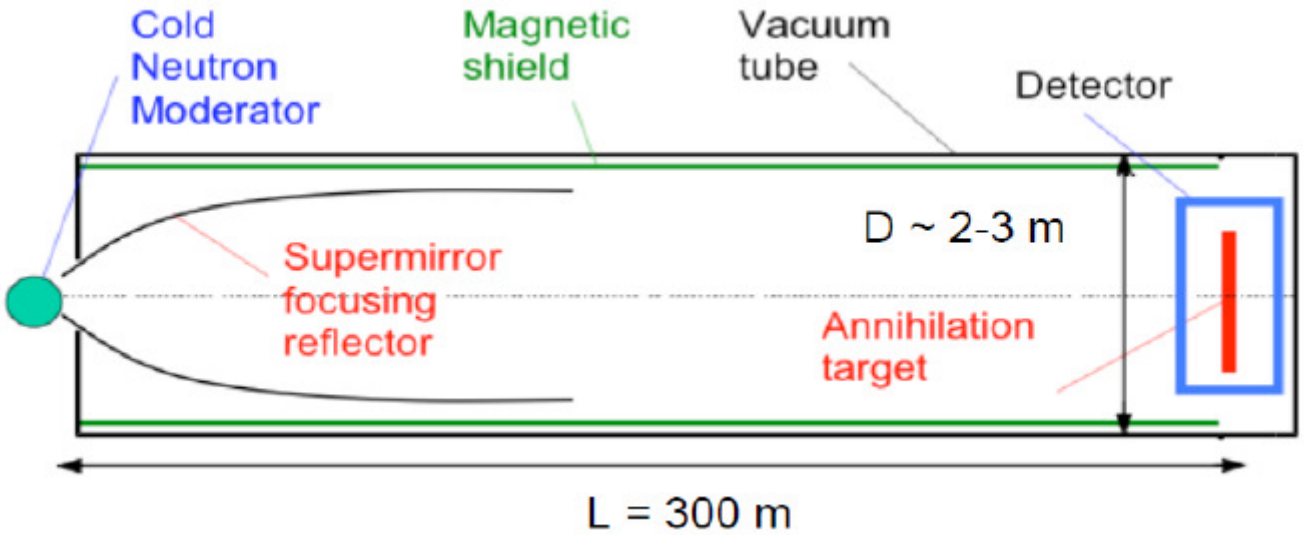


2 GeV protons (3ms long pulse, 14 Hz) hit rotating tungsten target.

Cold neutrons after interaction with moderators.



Overview of the Experiment



Optimise sensitivity = $N_n t^2$

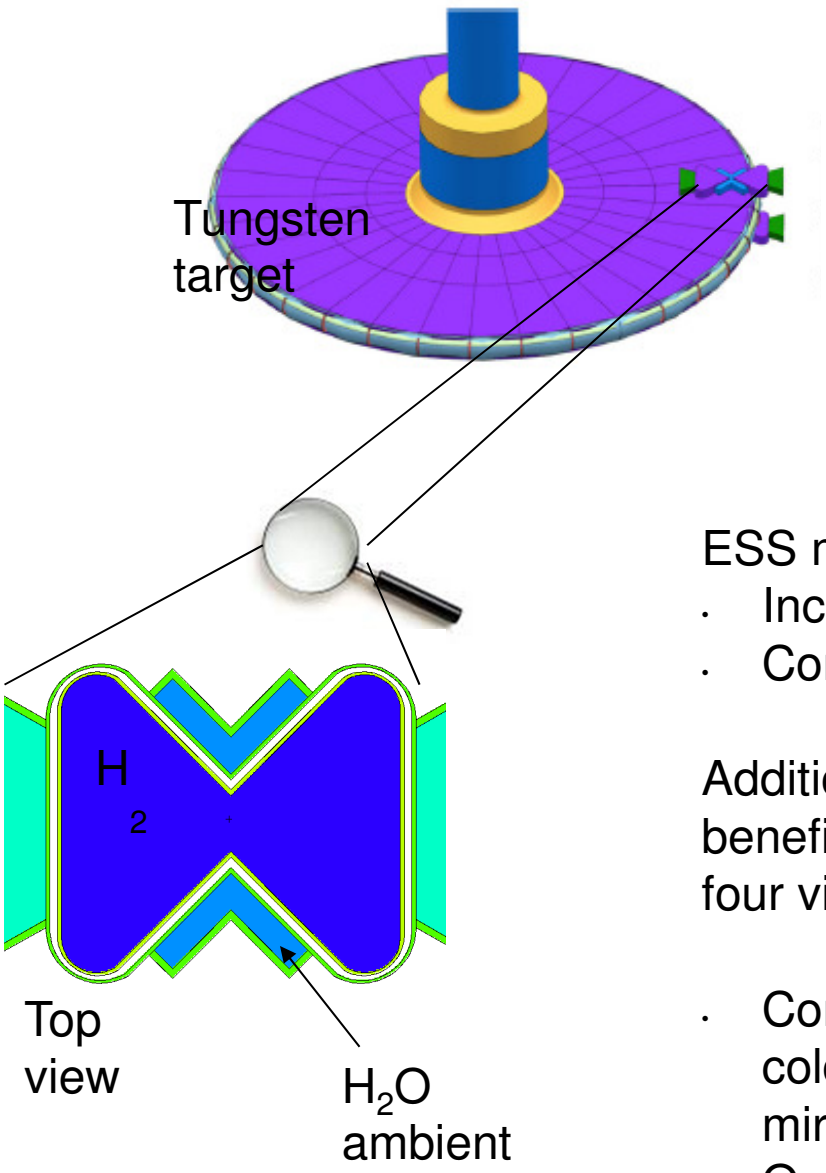
N_n = free neutron flux at target; t = transit time

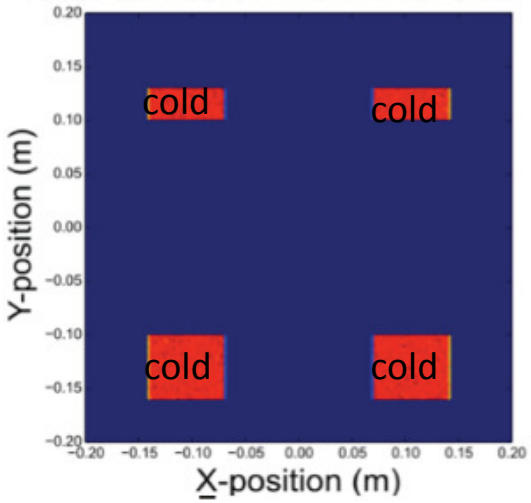
- Cold neutrons (E<5 meV, v<1000ms^{-1})
- Low neutron emission temperature (50-60 K)
  - Supermirror transmission and transit time
- Large beam port option, large solid angle to cold moderator.

Increase in sensitivity for $P_{n\bar{n}} \sim 10^3$ compared to previous experiment (ILL)

- Neutron guiding, larger opening angle, higher flux, particle ID technologies, running time.

Neutronics





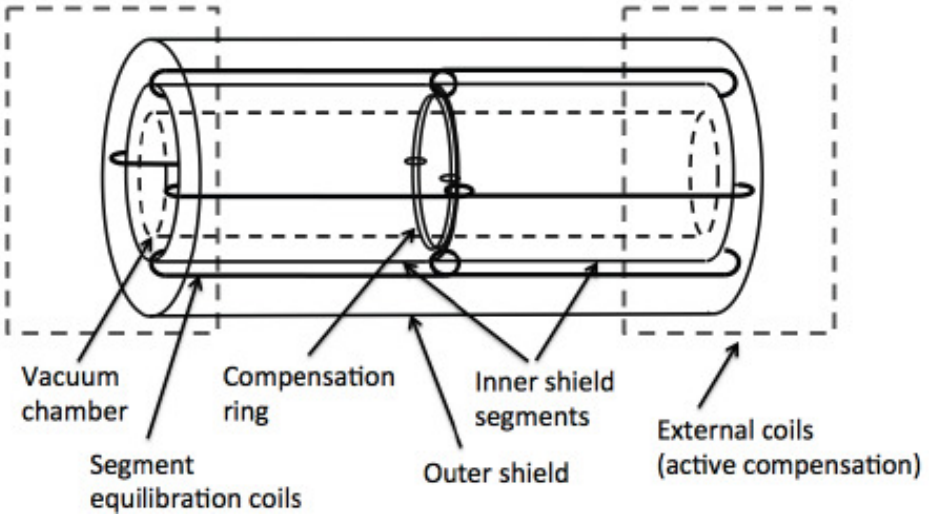
ESS moderators will be of “Butterfly” design

- Increase cold yield
- Convenient beam extraction

Additional challenge for nnbar which could benefit from extracting neutrons from all four visible cold surfaces

- Conventional point-to-point focusing of a cold neutron beam using ellipsoidal mirrors inefficient.
- Ongoing studies on neutron optics

Shielding



Energy difference of $n, \overline{n}$ in B-field: $\Delta E = -2\vec{\mu} \bullet \vec{B}$

$\Rightarrow$ Magnetic shielding for flight volume

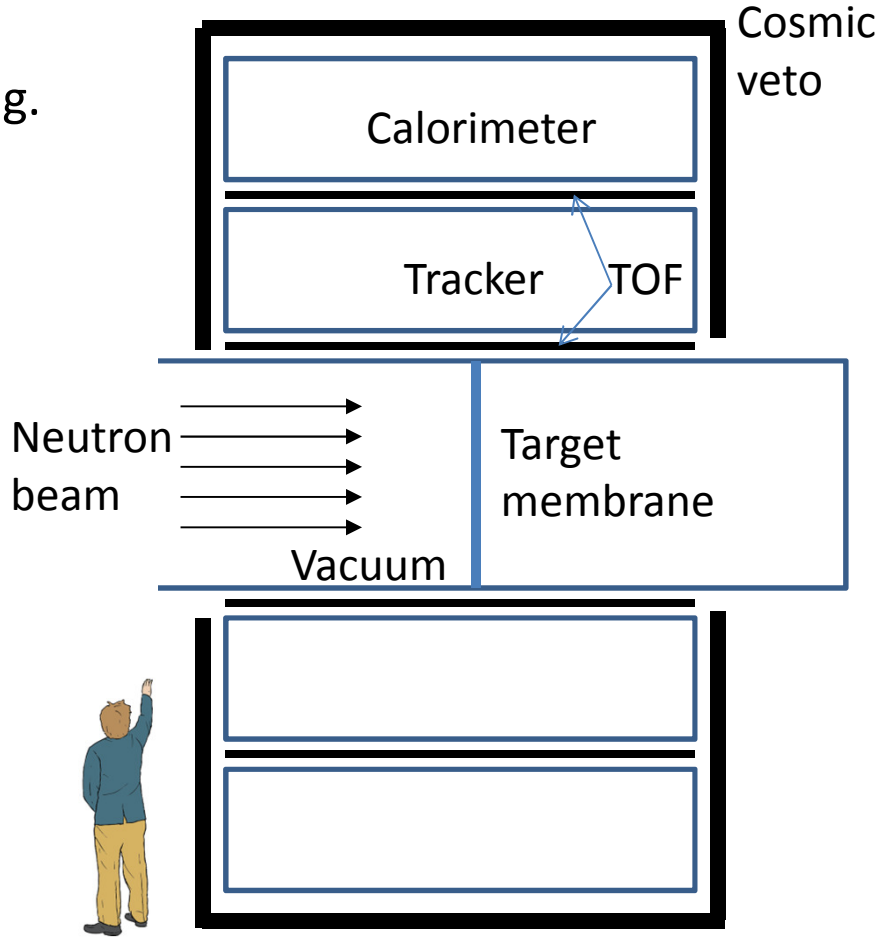
- $B <$ 5nT, $P \sim 10^{-5}$mbar
- Aluminium vacuum chamber
- Passive magnetic shield from magnetizable alloy
- External coils for active compensation
- Background studied by turning on/off $\vec{B}$-field.

Detector

Expect $n + \bar{n} \rightarrow \sim 5\pi$ at $\sqrt{s} \sim 2$ GeV.

Detector design for high efficiency and low bg.

- Annihilation target - carbon sheet
- Tracker - vertex reconstruction
- Time-of-flight system
  - scintillators around tracker.
- Calorimeter
  - lead + scintillating and clear fibre.
- Cosmic veto - plastic scintillator pads
- Trigger - Track and cluster algorithms



Collaboration and approximate timescales

Several workshops (CERN, Lund)
Collaboration formed – interim spokesperson G. Broojimans
Expression of Interest submitted to ESS.
Signatories from 26 institutes , 8 countries.

More collaborators are welcome!

ESS $n\bar{n}$

Commissioning, Intensity ramp, early experiments

2019
Construction, commissioning, early data-taking

Initial user program

2023
Physics runs

Routine operations

2026
End run, complete analysis

Summary and outlook

- The search for neutron-antineutron oscillations addresses open questions in modern physics.
- An experiment at the ESS offers a new opportunity to extend sensitivity to neutron oscillation probability by several orders of magnitude and set a new limit on the stability of matter.
- Collaboration formed and EOI submitted
- Provisional schedule made
- **New collaborators welcome!**
  - **Next workshop 27th-28th August in Gothenburg**
  - **Open to collaboration members and those who are interested in potentially joining.**
  - **https://indico.esss.lu.se/indico/event/349/**