HIBEAM and NNBAR at the European Spallation Source

University of Washington
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Outline

- The European Spallation Source
- Motivation and current state of the art
- NNBAR project
- HIBEAM as a stepping-stone

The European Spallation Source

ESS is the next generation European neutron scattering facility now under construction in Lund, Sweden

- Consortium of 13 European countries
- Construction started 2014
- Now ~85% complete
- User operations start 2027

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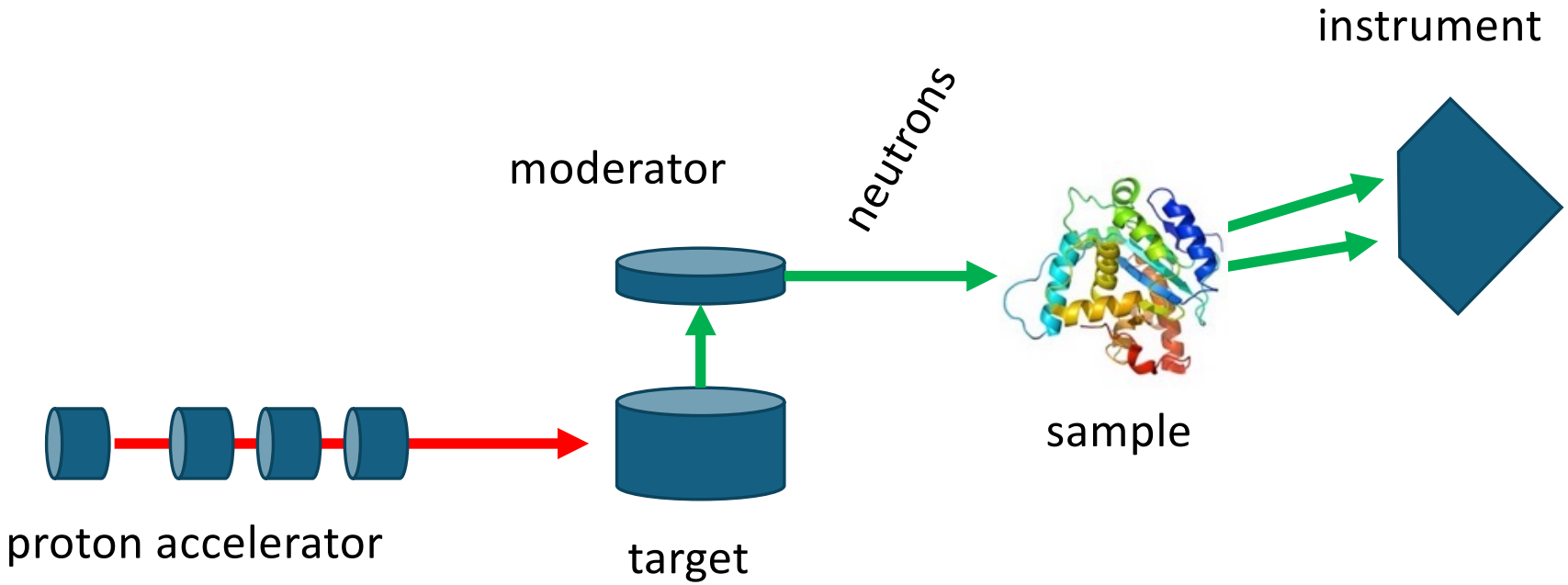
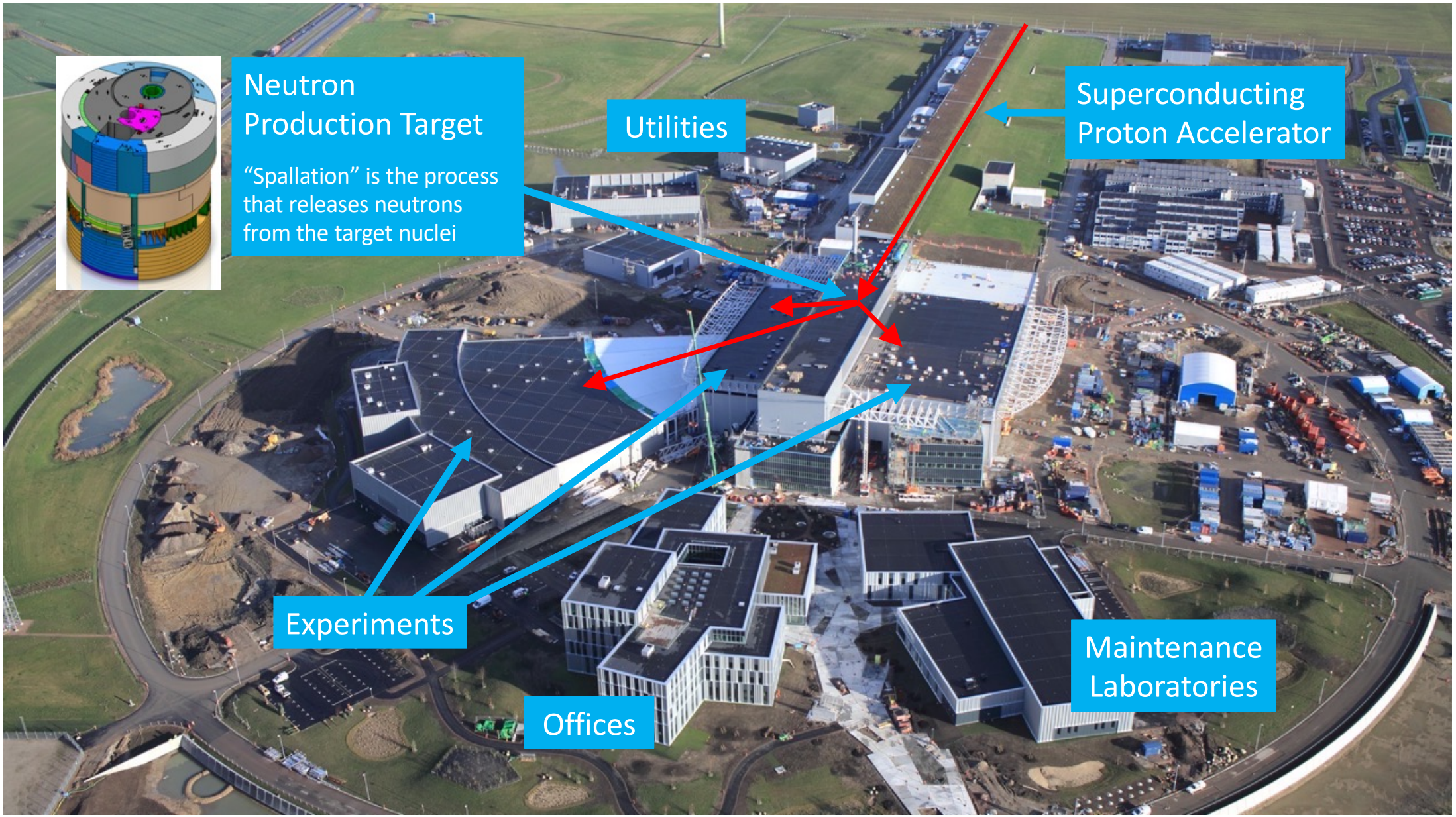
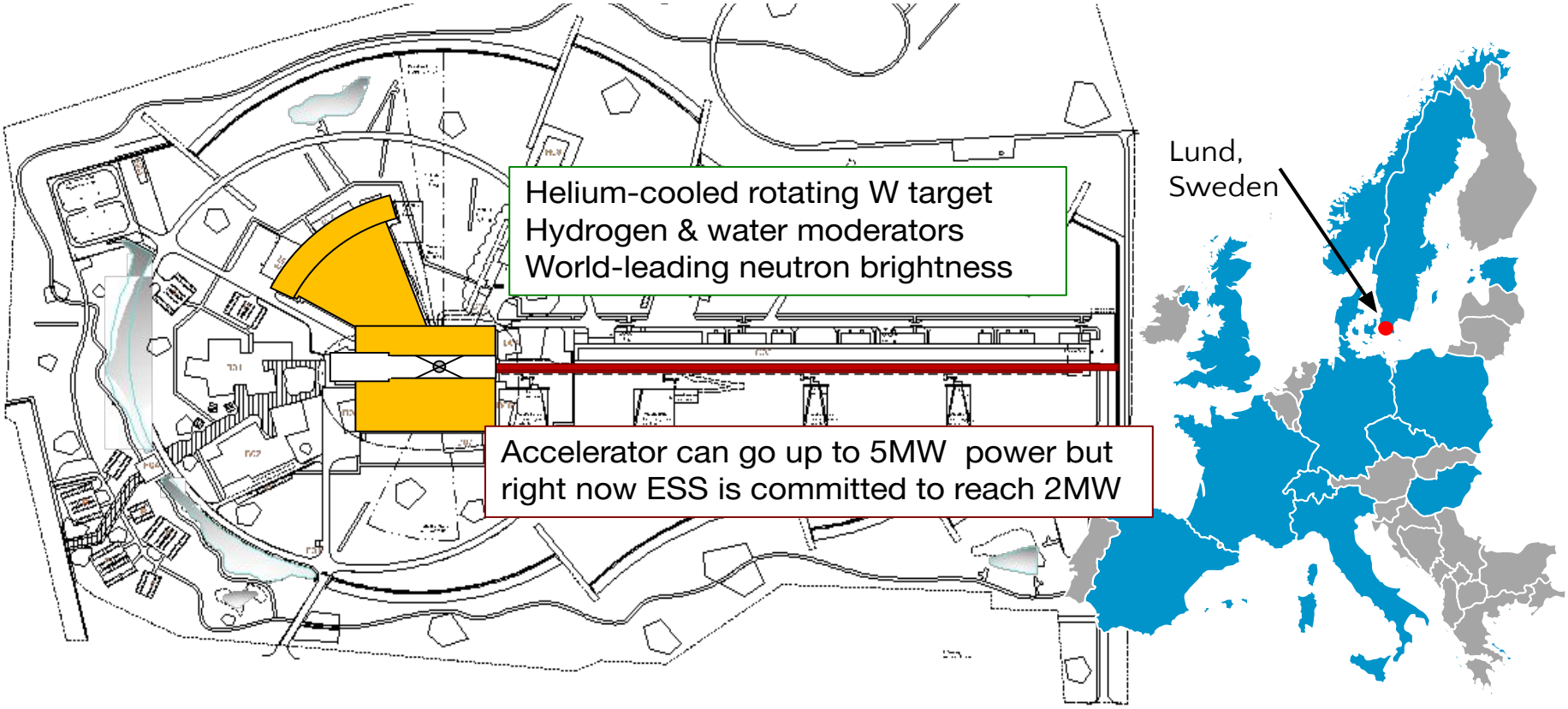
How a spallation neutron source works



"spallation" is the process that releases neutrons from the target nuclei


Neutron
Production Target
“Spallation” is the process that releases neutrons from the target nuclei
Utilities
Superconducting
Proton Accelerator
Experiments
Offices
Maintenance
Laboratories



15 neutron instruments approved and under construction

First beam on target end 2025; first science in 2026-27

22 instruments foreseen eventually

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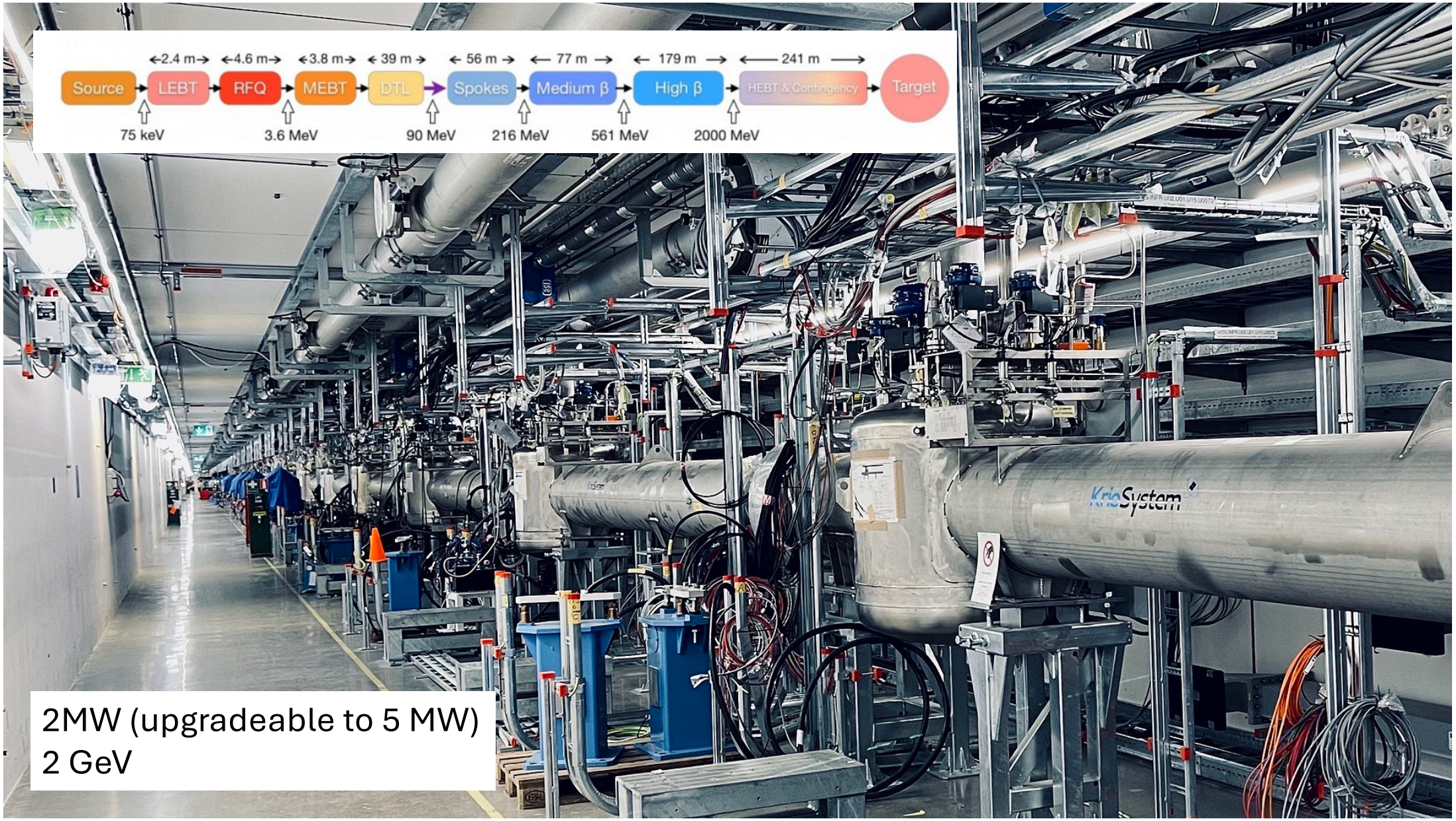
September 2014
EUROPEAN
SPALLATION
SOURCE

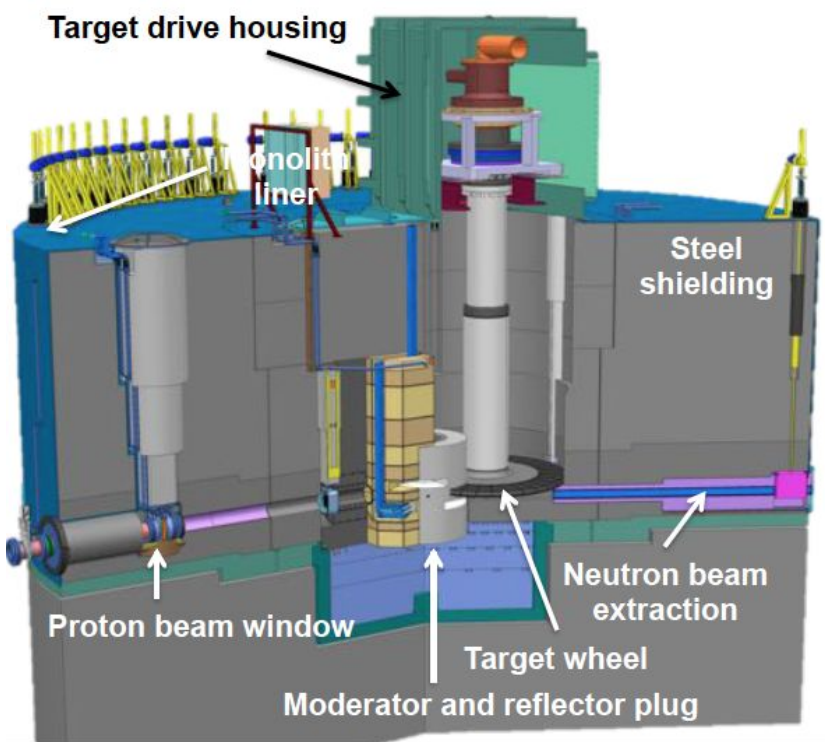

2019


2022

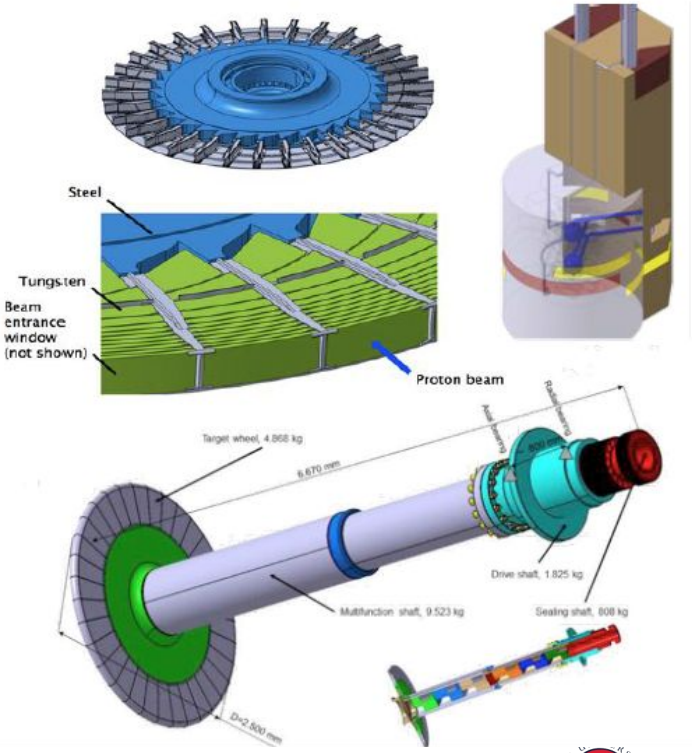

←2.4 m→
←4.6 m→
←3.8 m→
← 39 m →
← 56 m →
← 77 m →
← 179 m →
← 241 m →
Source
LEBT
RFQ
MEBT
DTL
Spokes
Medium β
High β
HEBT & Contingency
Target
75 keV
3.6 MeV
90 MeV
216 MeV
561 MeV
2000 MeV
2MW (upgradeable to 5 MW)
2 GeV

Inauguration of the ESS ion source - an in-kind contribution from Italy, with HM the King of Sweden and HE the President of the Italian Republic

Neutron production target



Target wheel



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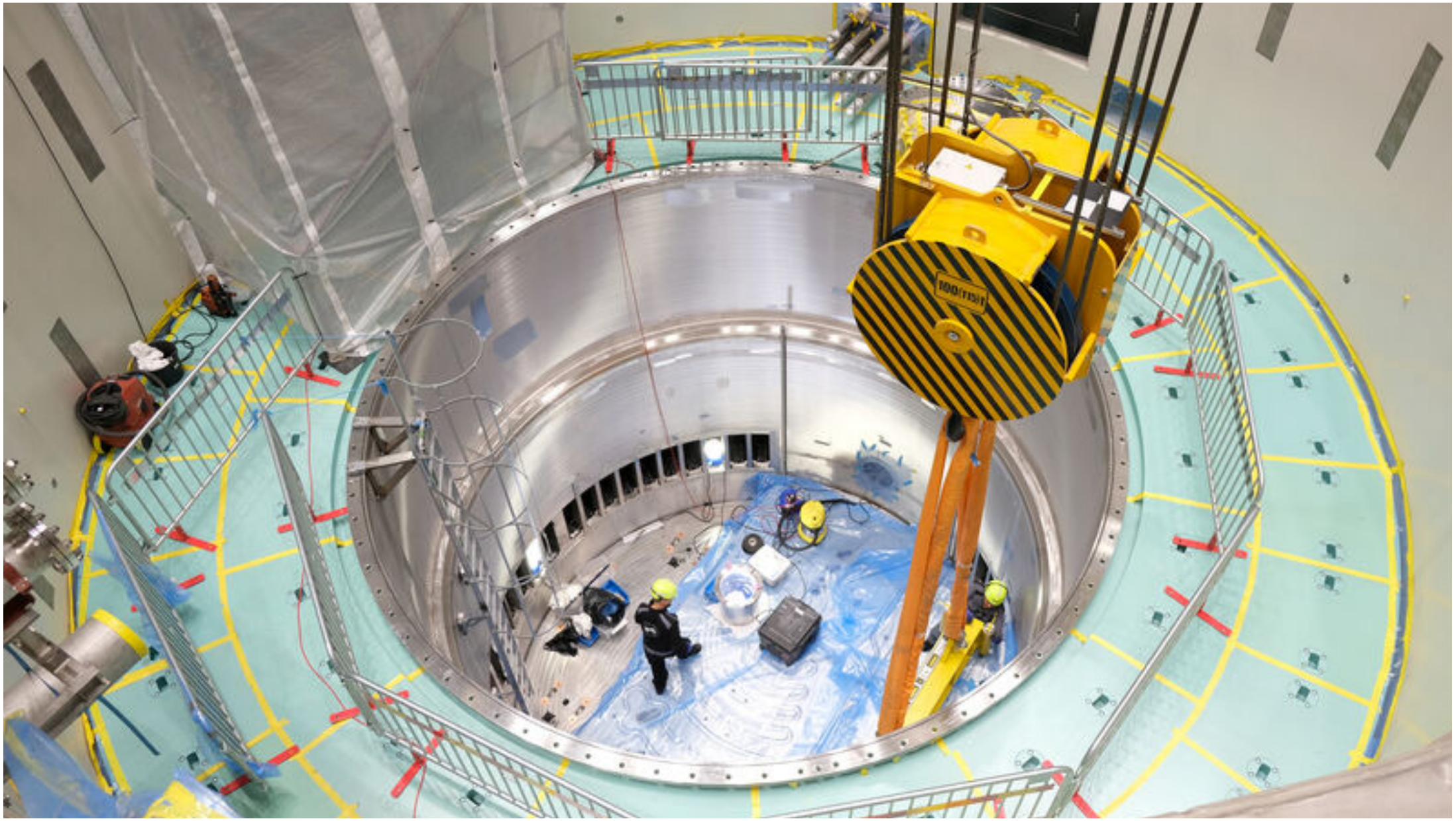
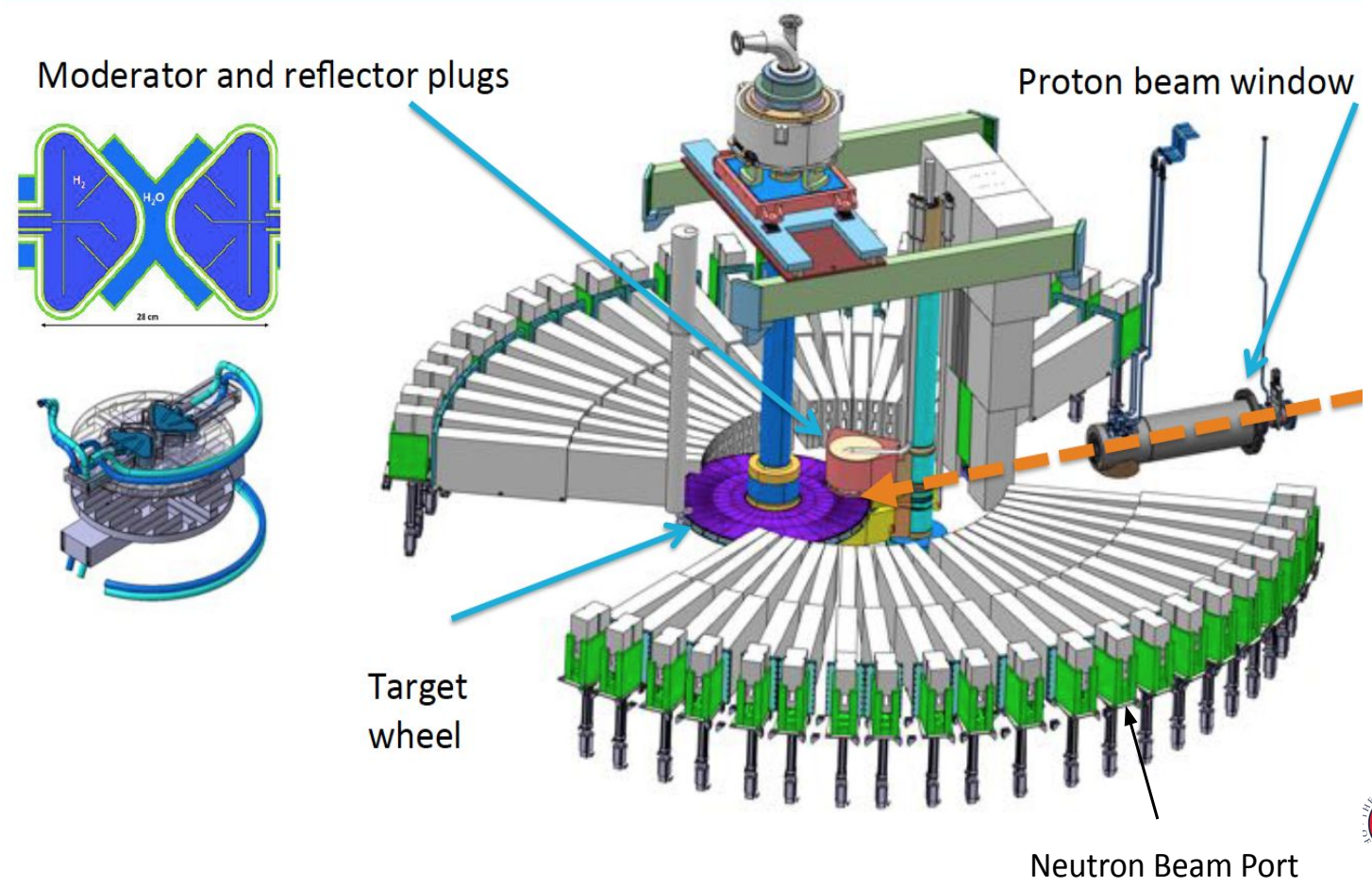


Neutron beam extraction



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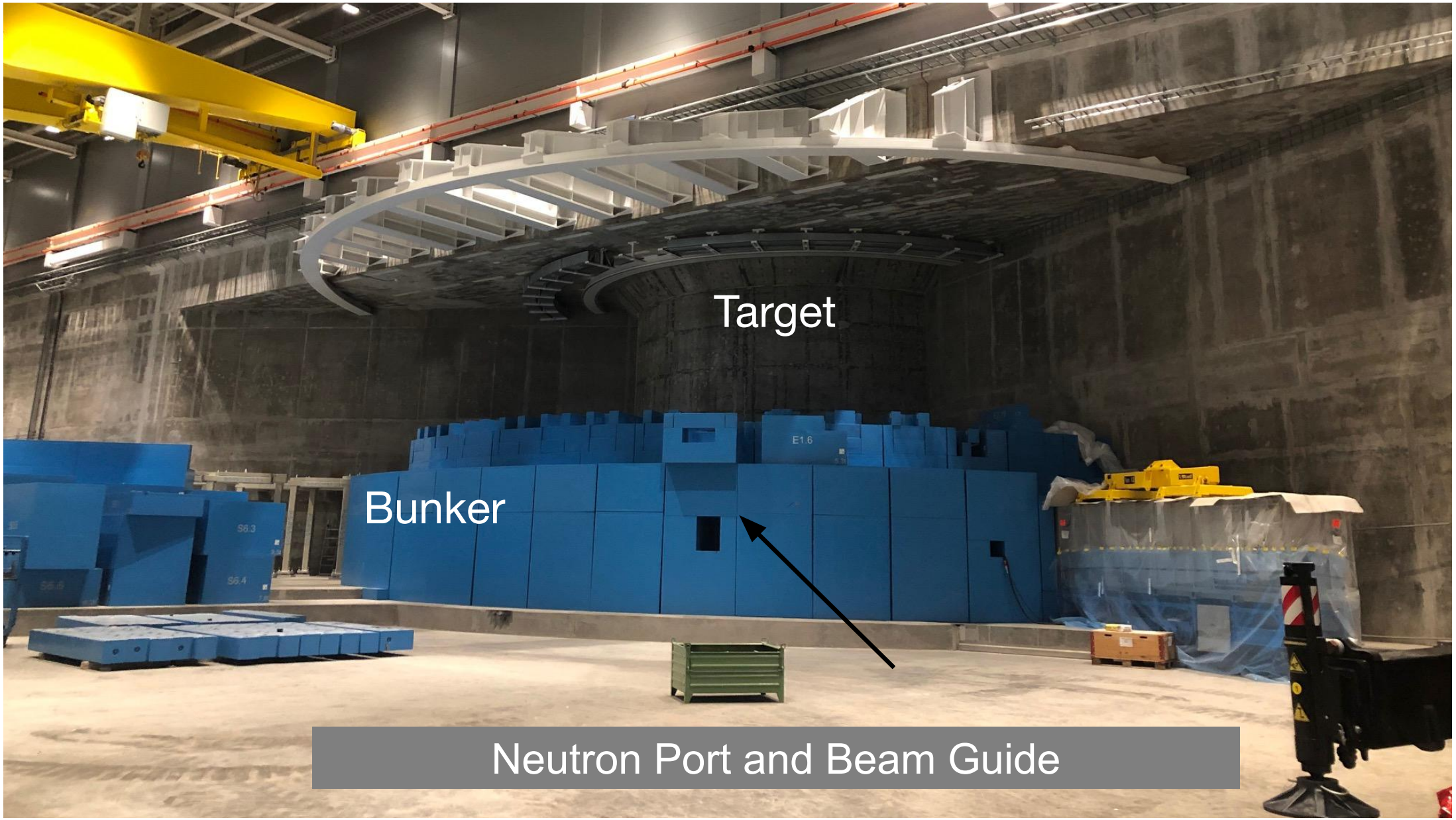
STEINE
STEINESS
Rental


RESTRICTED AREA
enwesa


Target
Bunker
Neutron Port and Beam Guide

Particle physics at ESS

- ESS business case based on delivering neutron fluxes for materials science and biology that are 10–20 x higher than existing facilities
- 2MW (eventually 5MW) proton beam, ~ 2 GeV, 3 ms pulse @14Hz
- Potential for high impact physics with neutrons (and neutrinos)
- 2015 expression of interest to ESS attracted ~ 100 authors from 26 institutes
- In 2018, Science Advisory Committee identified Particle Physics as one of the highest priority capability gaps for ESS

Why search for neutron oscillations?

- In the absence of new physics at colliders, pursue all avenues
- BNV one of Sakharov conditions for matter-dominated universe
- Explore all the possibilities for $\Delta B, \Delta L, \Delta(B+L) \neq 0$:

  Proton decay e. g. $p \to \pi^0 + e^+$: $\Delta B \neq 0, \Delta L \neq 0$
  $0\nu\beta\beta$: $\Delta B = 0, \Delta L = 2$
  Neutron-antineutron oscillation: $\Delta B = 2, \Delta L = 0$

- Search for $n \to \bar{n}$ sensitive to the PeV scale for new physics

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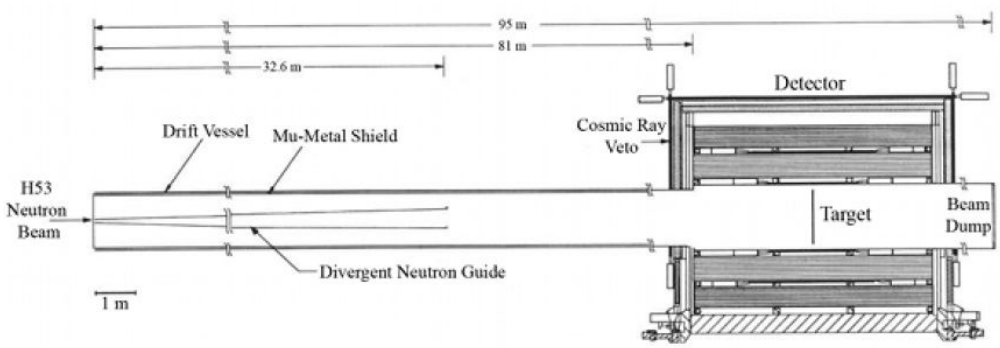
Current state of the art



Free neutron oscillation search at ILL (1995)

- 58MW research reactor in Grenoble
- 100m propagation in field-free region
- $\bar{n}$ annihilation in 130 μm carbon target
- 0 events observed with 0 background expected: $\tau > 0.86 \times 10^8 \mathrm{s}$

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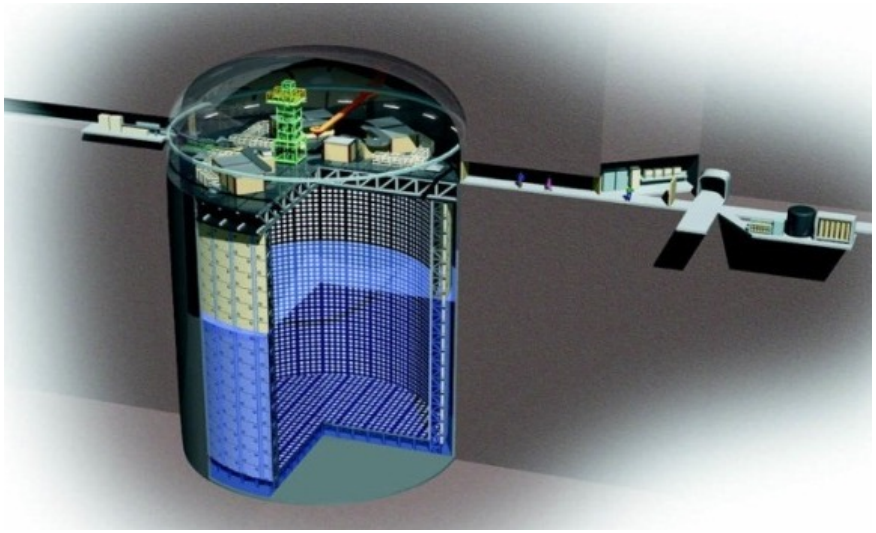

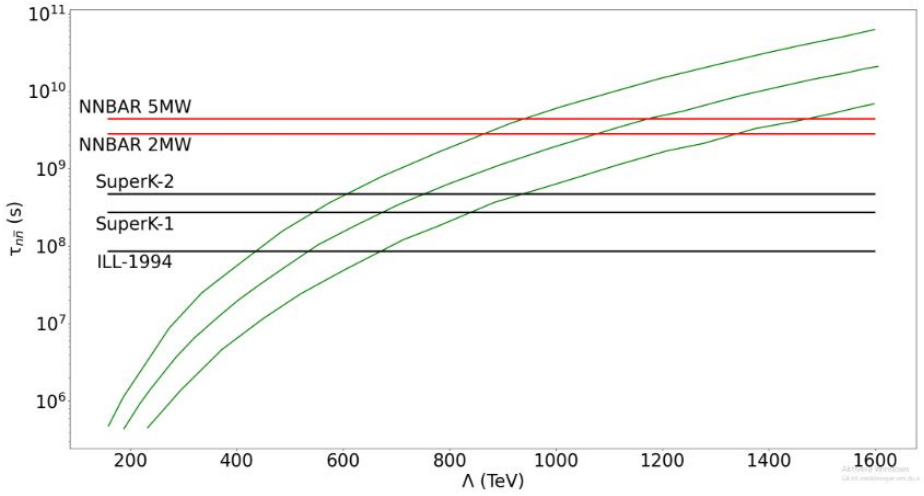

Bound neutrons – best limits from Super Kamiokande

- $n \rightarrow \bar{n}$ followed by $\bar{n}$ annihilation and disintegration
- Nuclear interactions: model dependent
- Not background free

$$\tau > 4.7 \times 10^{8}\,\mathrm{s}$$

We are probing the PeV scale!

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NNBAR

- High sensitivity free neutron search for $n \to \bar{n}$
- 200m decay path
- New large beam port
- second moderator

Goal: × 1000 improvement over ILL

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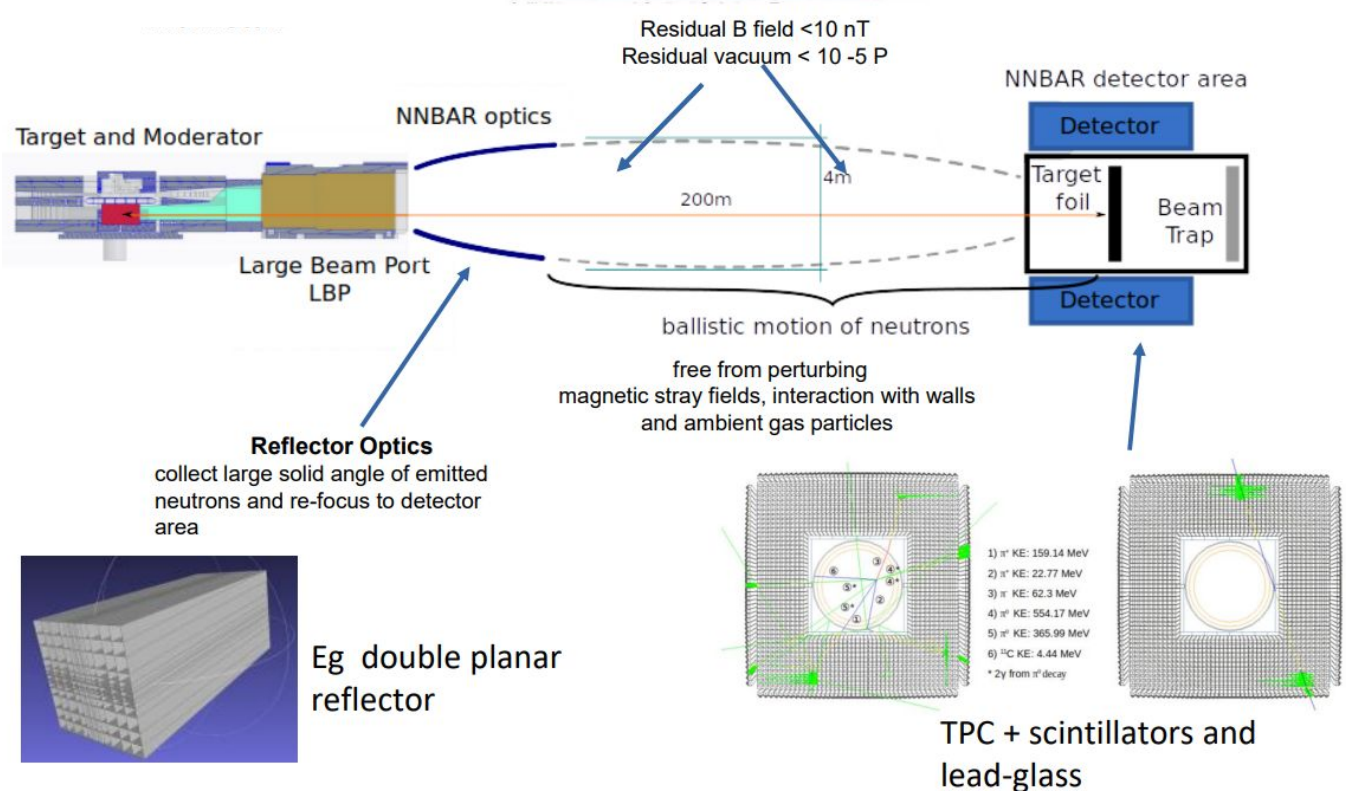
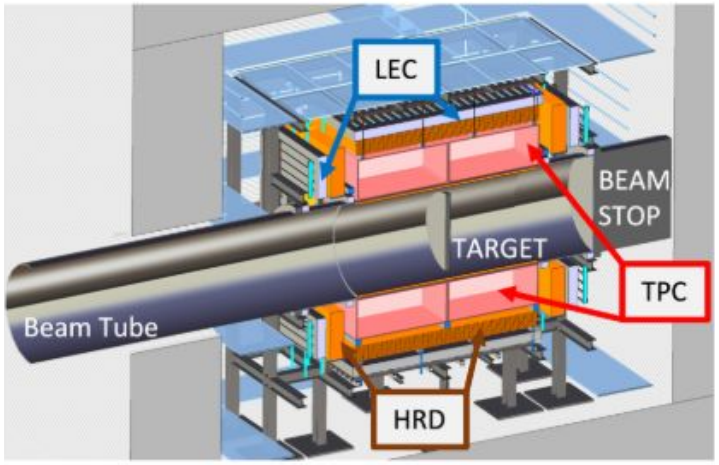
NNBAR design





Detector

Pionic final state $\sqrt{s} \sim 2\ GeV$

TPC for $\pi^{\pm}$

Lead glass calorimeter for π^{0}

Scintillator staves

Cosmic veto

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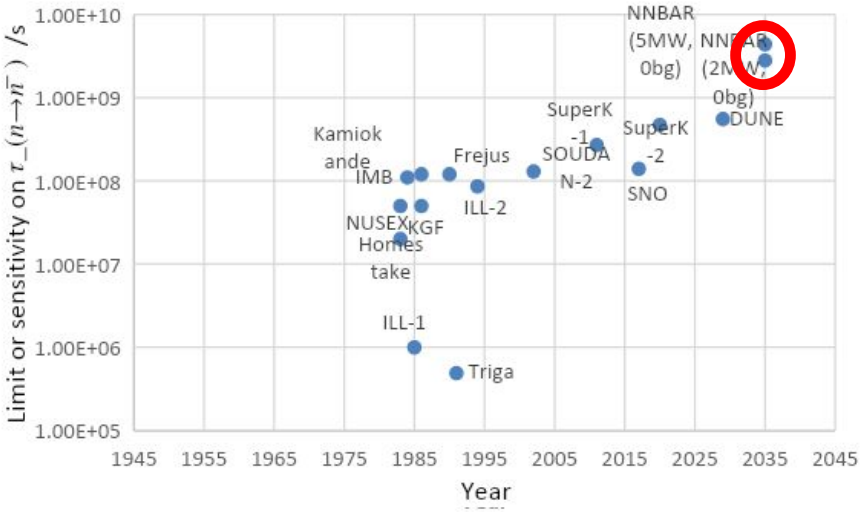
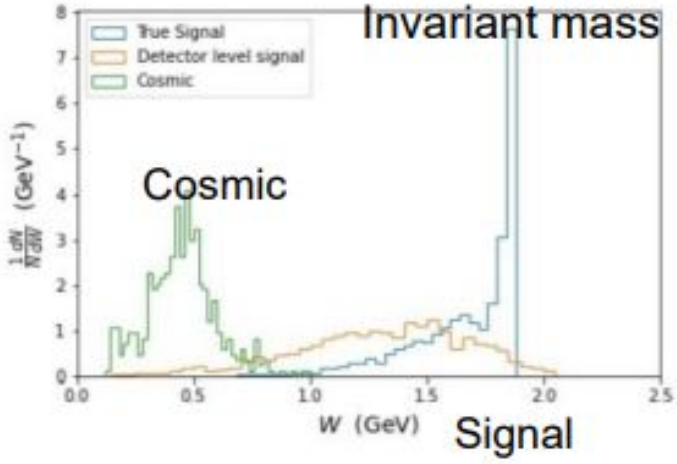
NNBAR performance

- MCNP + GEANT4 beamline and detector simulation
- Background suppression criteria developed





Delivers desired increase in sensitivity

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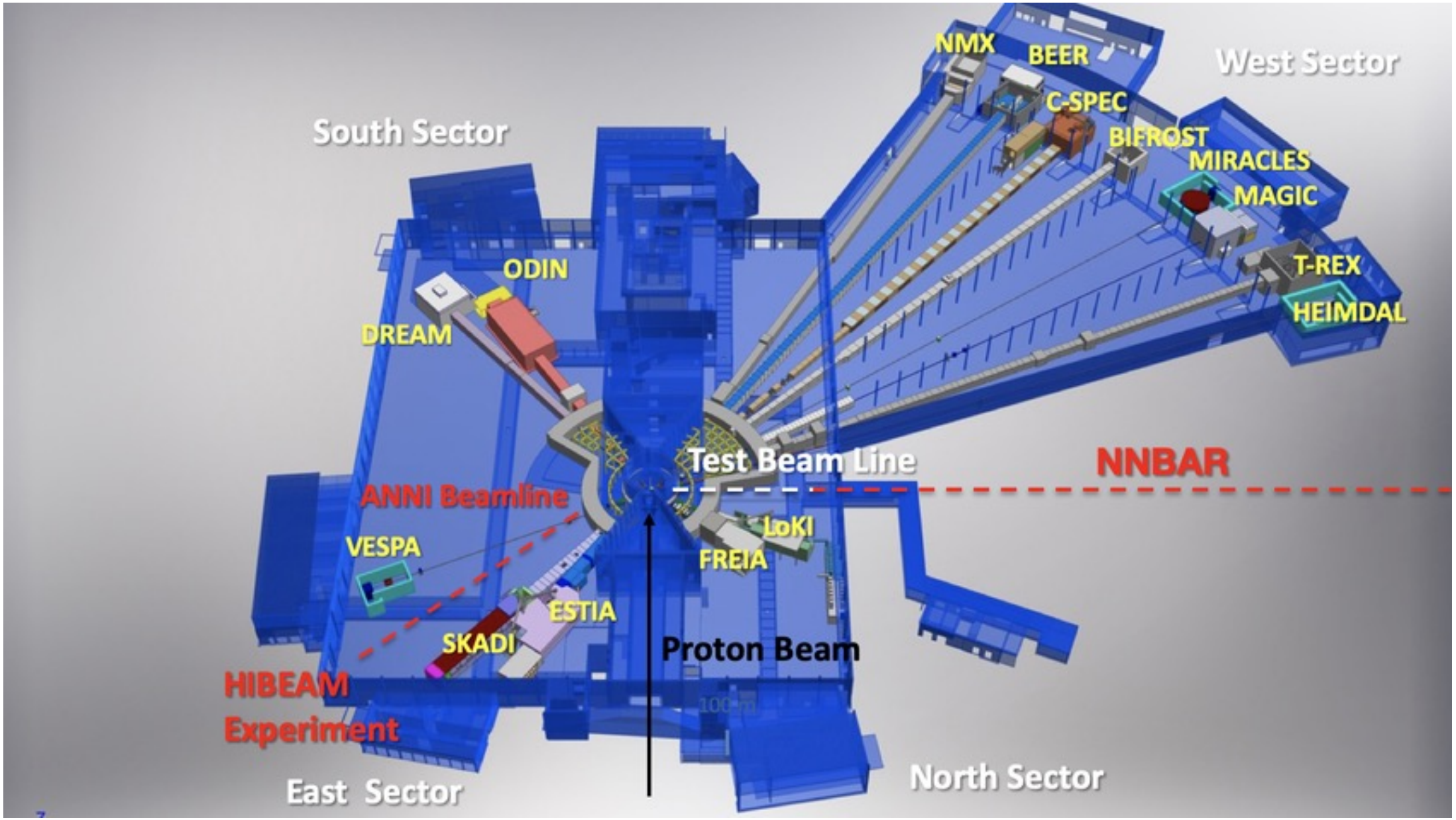
HIBEAM

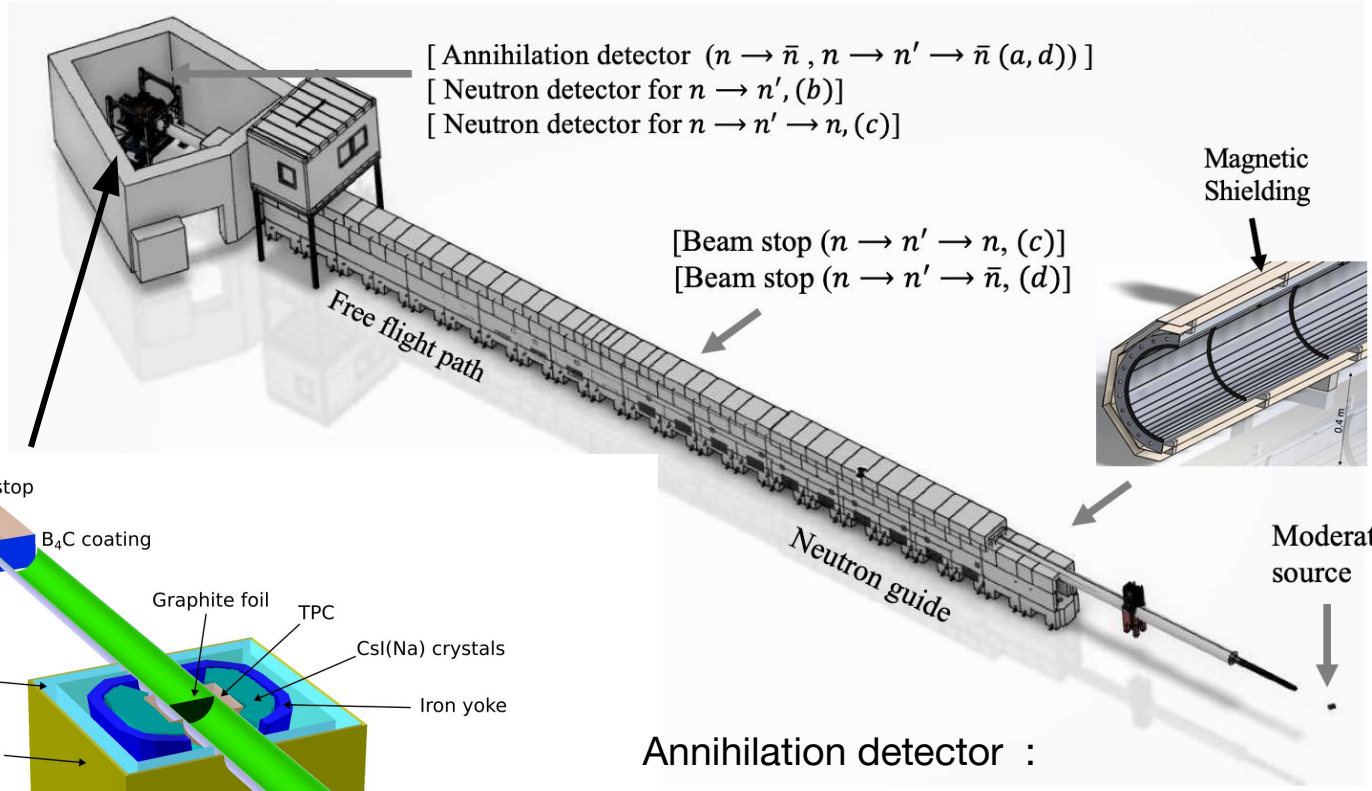
NNBAR conceptual design shows what is possible

… but requires new large beam port and a second moderator,
a new enclosure and long beamline with magnetic shielding

ESS priorities and funding will remain constrained until the 2030s

Develop the HIBEAM concept as a stepping-stone


NMX
BEER
West Sector
C-SPEC
South Sector
BIFROST
MIRACLES
MAGIC
ODIN
T-REX
DREAM
HEIMDAL
Test Beam Line
NNBAR
ANNI Beamline
LoKI
VESPA
FREIA
ESTIA
SKADI
Proton Beam
HIBEAM
Experiment
East Sector
North Sector



Annihilation detector :

The neutron beam will hit a thin carbon foil target
The carbon has large $\bar{n}$ annihilation cross section , mostly transparent to neutrons
$\bar{n}N \rightarrow$ <5> pions (1.8 GeV)

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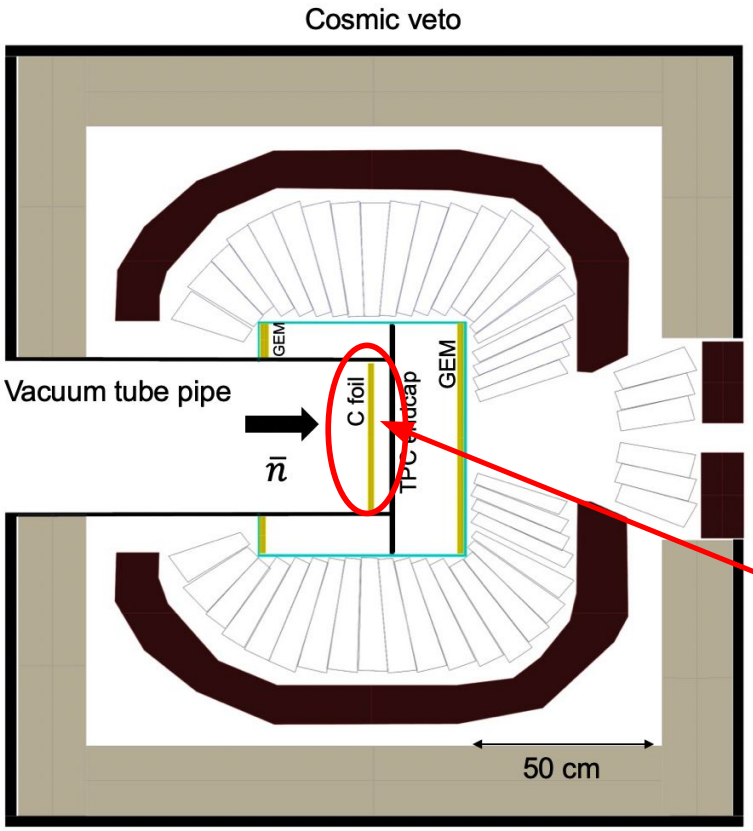
HIBEAM detector



Pionic final state $\sqrt{s} \sim 2\ GeV$

TPC for $\pi^{\pm}$

Crystal or scintillator calorimeter for π^0

Option of using the existing WASA crystal calorimeter (Uppsala)

Cosmic shielding and veto counters (cosmics are the dominant background)

Carbon foil were the annihilation takes place

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Getting to HIBEAM

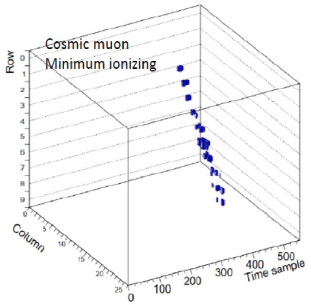
VR RFI

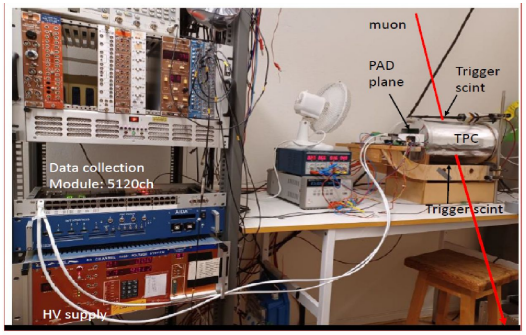
Stockholm, Lund, Chalmers, ESS

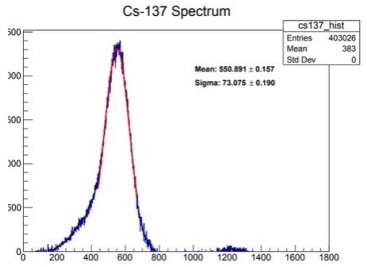
Prototype development

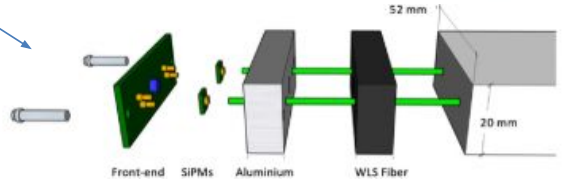
- TPC
- WASA crystal calorimeter
- Scintillator/lead-glass calorimeter

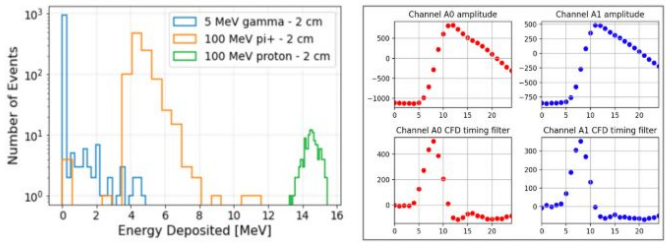
Annihilation detector
Neutron detector
Beamline design











Other physics with HIBEAM

- Search for sterile neutrons – regeneration target and scanning magnetic field
- Axion dark matter searches
- Potentially neutron EDM (repurposing the ORNL EDM apparatus)

Current Status

- ESS council has approved 1.1M€ for neutron extraction system
- Construction and testing of annihilation detector prototype components; validation and simulation; system integration at the ESS test beam line
- Preparatory support from European Commission, Swedish Research Council
- Institutes from Sweden, USA, Israel, France, Italy, Brazil, Australia
- Co-spokespersons: G. Brooijmans (Columbia), D. Milstead (Stockholm)
- Ready to move forward when construction funding is secured (~ 15 M€ for minimum configuration)

Conclusions

- ESS offers potentially very interesting new capabilities for particle physics
- HIBEAM beamline approved in principle, $\times 10$ improvement in discovery potential for $n \rightarrow \bar{n}$
- Ready to go once funding is secured
- NNBAR demonstrates the longer-term potential to explore two orders of magnitude further
- New collaborators welcome

Thank you!

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