The HIBEAM Experiment

HIBEAM & NNBAR – Search for neutron oscillations and beyond

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Stockholm University

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Baryon and lepton number violation

Standard Model (SM) of particle physics
does not describe nature completely:

- Matter-/antimatter asymmetry
- Dark matter
- Dark energy
- Grand unification (strong+electroweak)
- Gravity

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Sakharov conditions:

- Baryon number *B* violation
- *C*- and *CP*-symmetry violation
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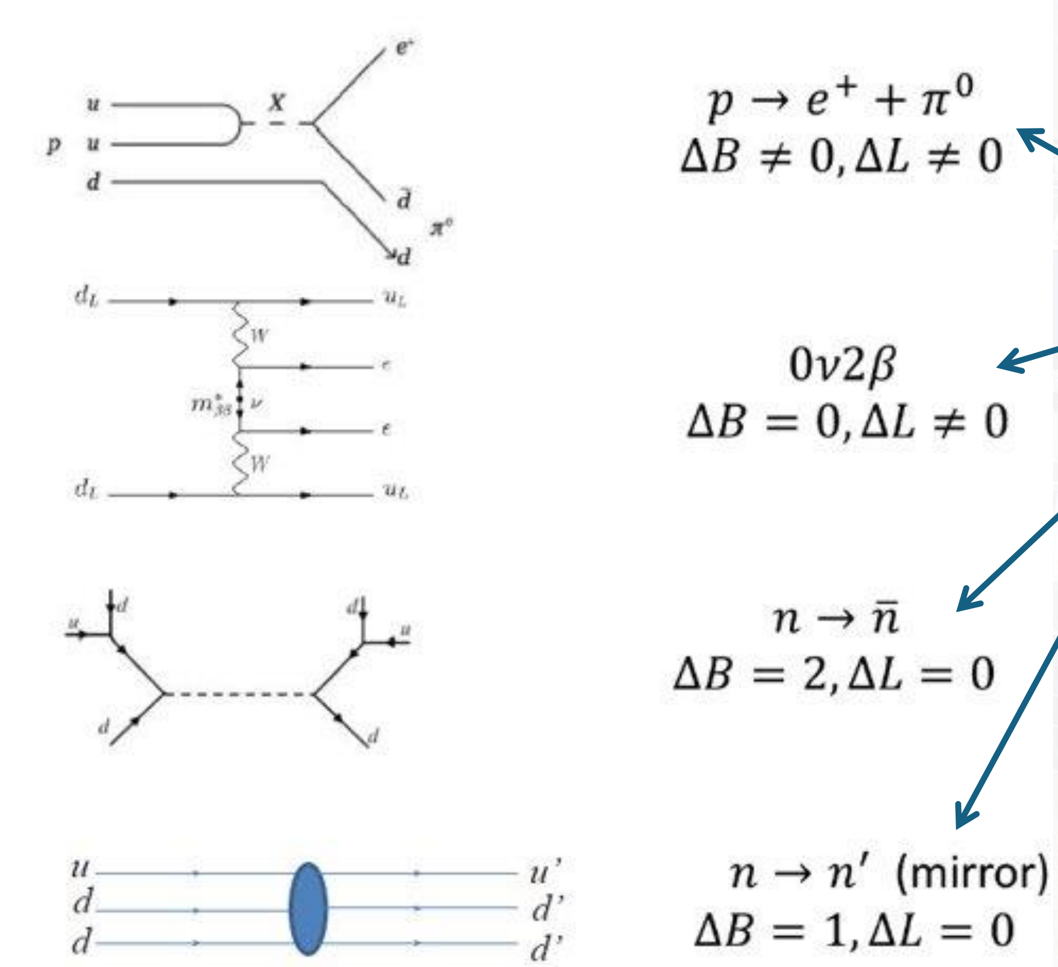
Baryon number violation (BNV) and lepton number violation (LNV) can arise together or independently:

- $\Delta B \neq 0 \quad \Delta L \neq 0 \quad \Delta[B-L] = 0$
- $\Delta B = 0 \quad \Delta L \neq 0 \quad \Delta[\mathrm{B}-L] \neq 0$
- $\Delta B \neq 0 \quad \Delta L = 0 \quad \Delta[B-L] \neq 0$

Different processes:

- Sphaleron processes
- Unification models
- Supersymmetry
- Hidden sector
- …

Baryon and lepton number violation



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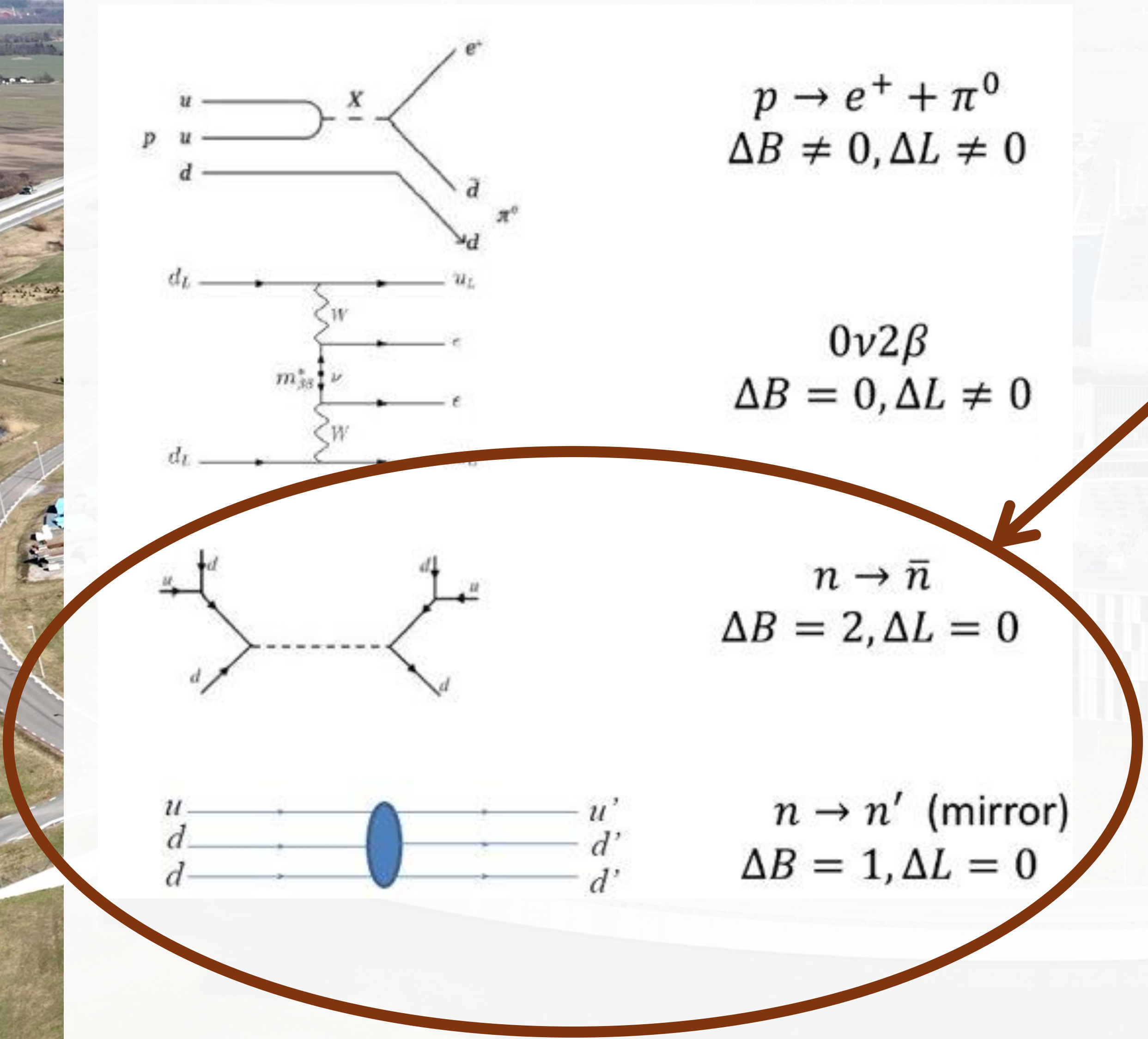

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  few searches: last free neutron/antineutron in 1990s

Different processes:

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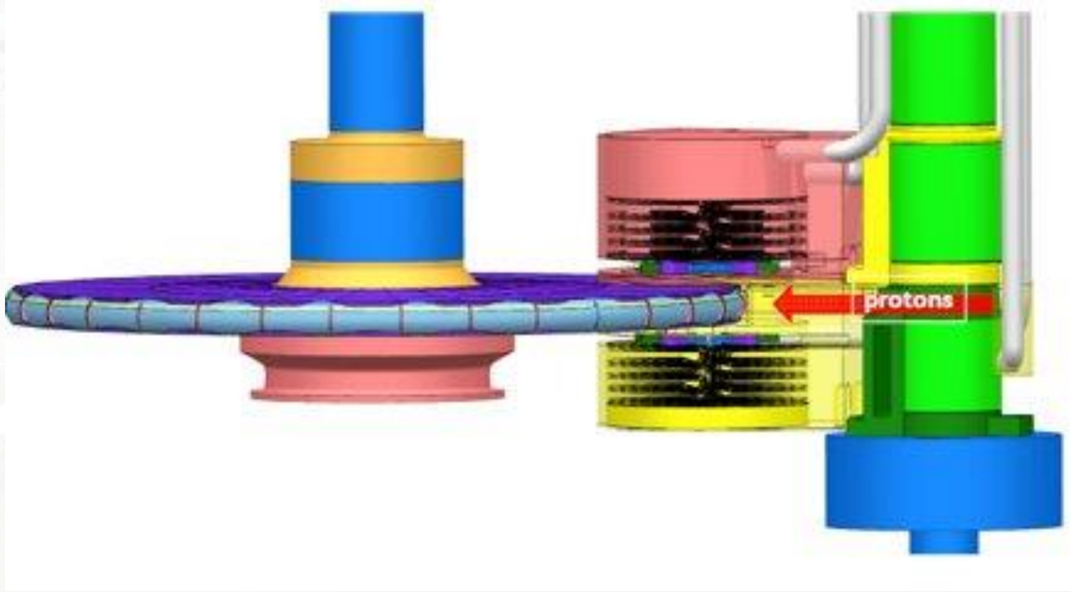
- Unification models
- Supersymmetry
- Hidden sector
- …

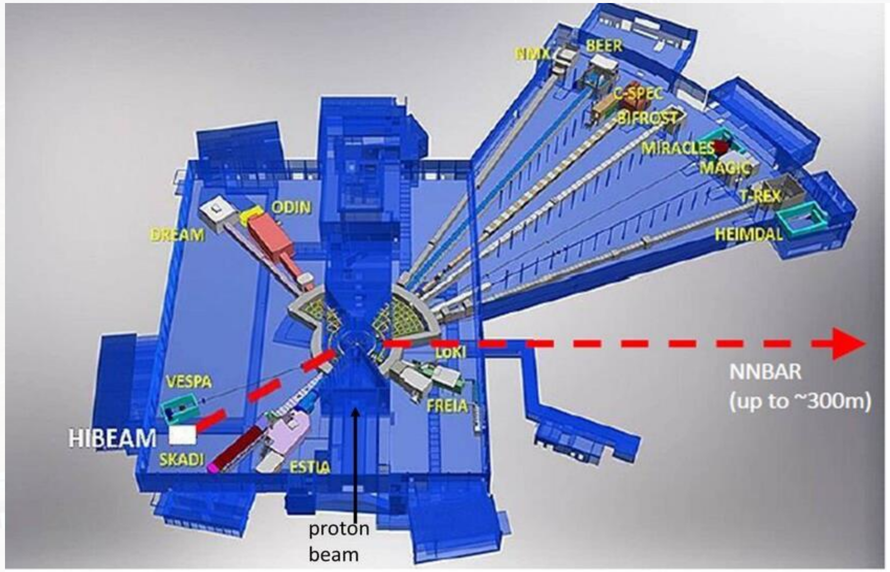
The European Spallation Source (ESS)

- Multi-disciplinary research centre
  - o The world's highest intensity source of spallation neutrons
- 17 European nations participating
- Lund, Sweden
  Hosts: Sweden, Denmark
- Start operations in 2027/2028.



- Spallation neutrons:
  - o Nominally 2 GeV protons
    3 ms pulse, 14 Hz, (2;5) MW
  - o Rotating tungsten target
- Neutrons cold after interaction with moderators
- 15 beamlines/instruments

Beamlines and the proposed HIBEAM/NNBAR program



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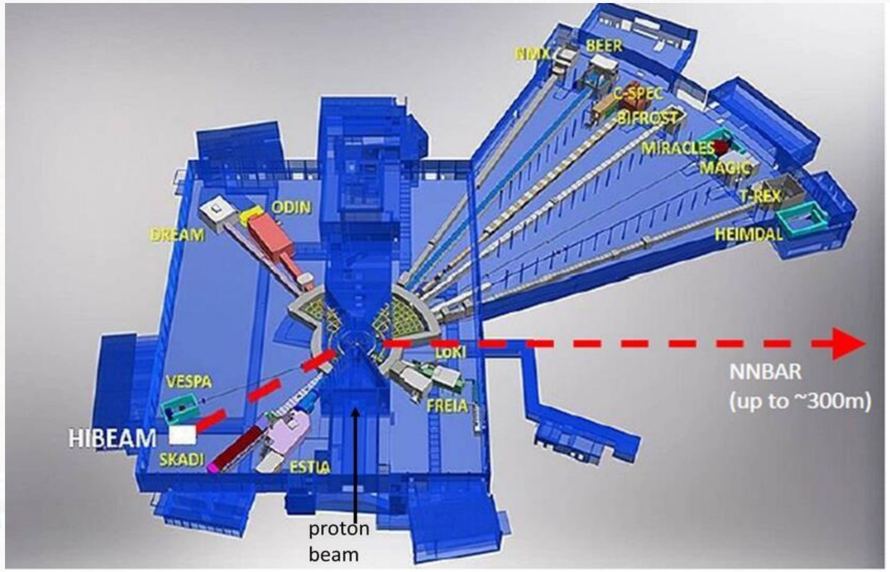

R&D
Annihilation detector prototype
Conceptual design reports for HIBEAM/NNBAR

TDRs and small scale experiment at ESS

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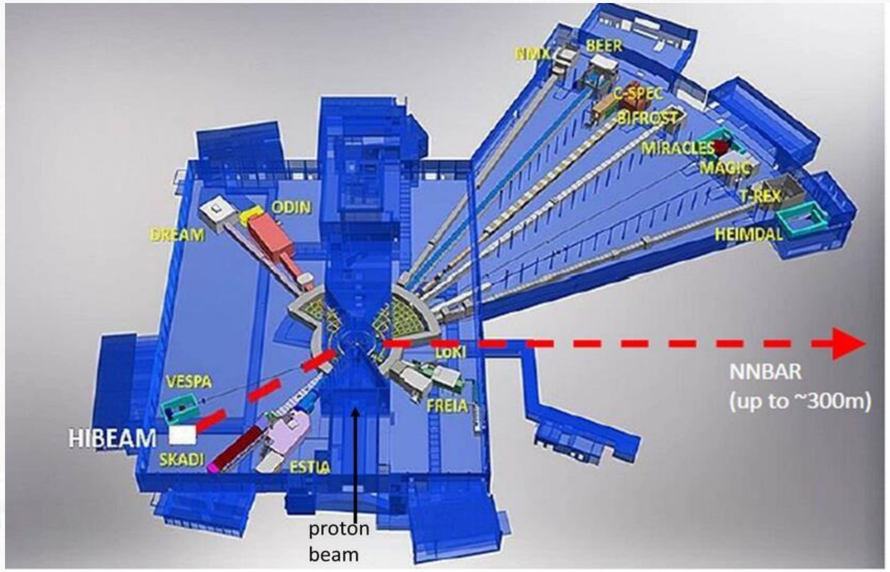

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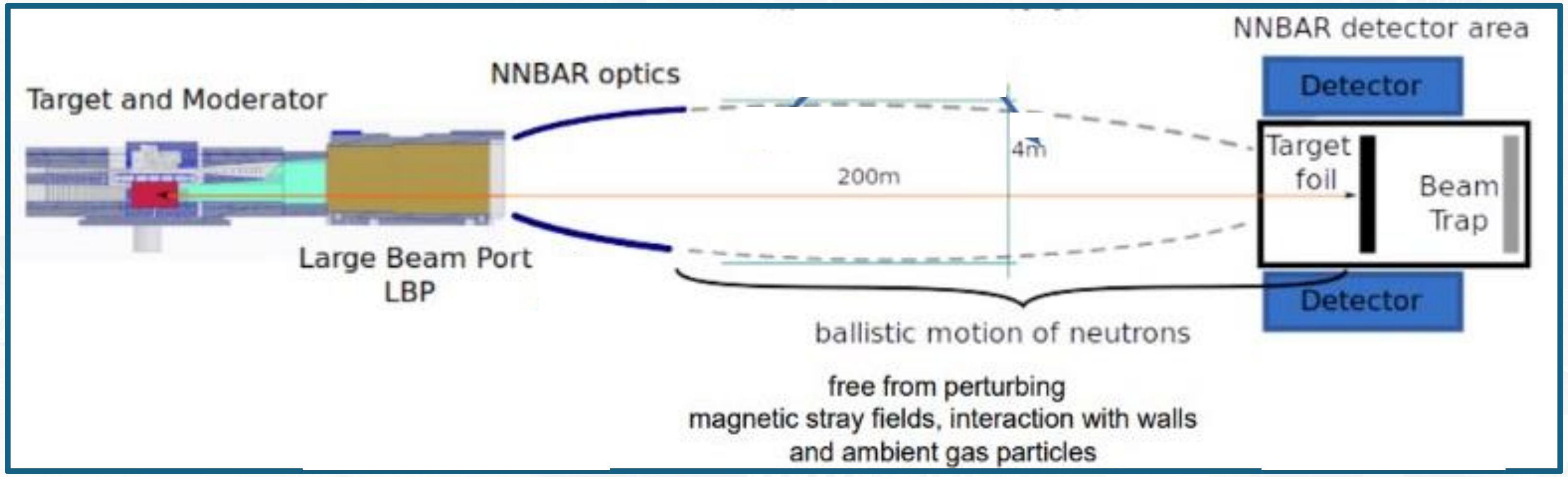
HIBEAM
High precision induced:
$n \rightarrow n'$, $n \rightarrow \bar{n}$ (x10 improvement)
First search for free $n \rightarrow \bar{n}$ at a spallation source

NNBAR
High sensitivity free $n \rightarrow \bar{n}$ (x1000 improvement)
At the Large Beam Port

The NNBAR experiment



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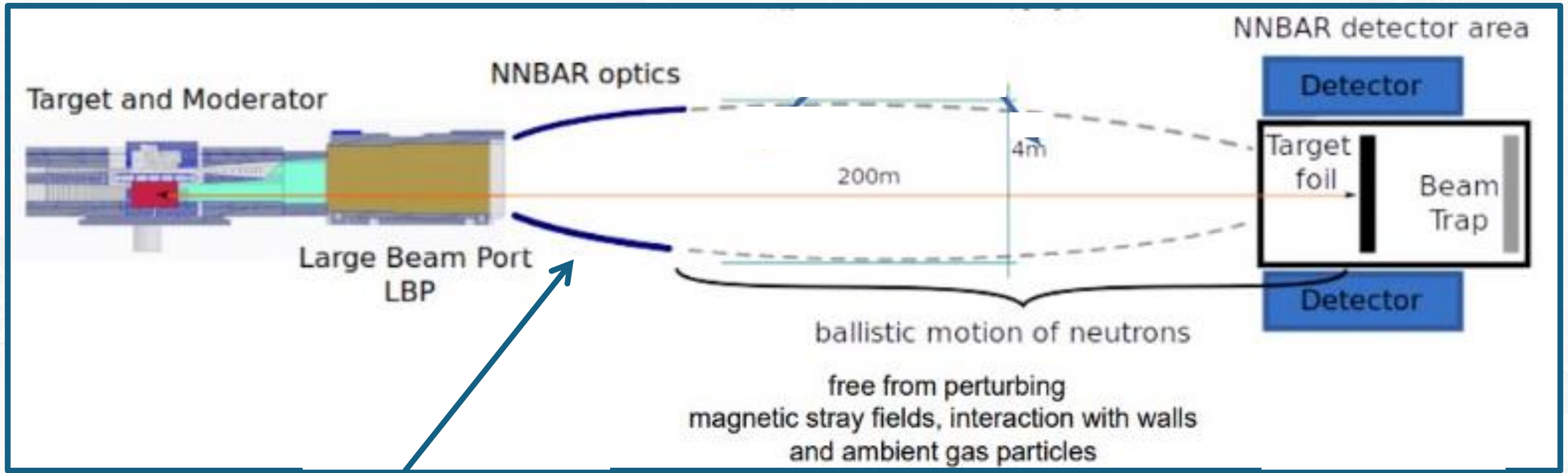
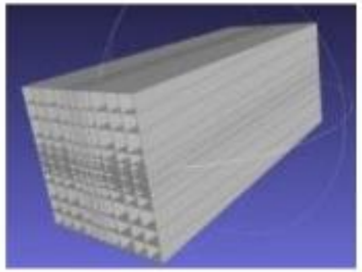


Reflector Optics

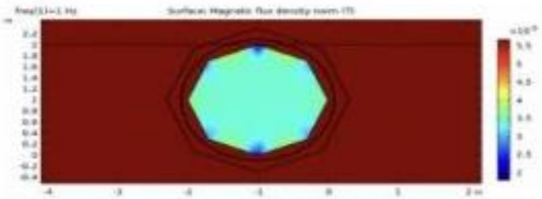
collect large solid angle of emitted neutrons and re-focus to detector area



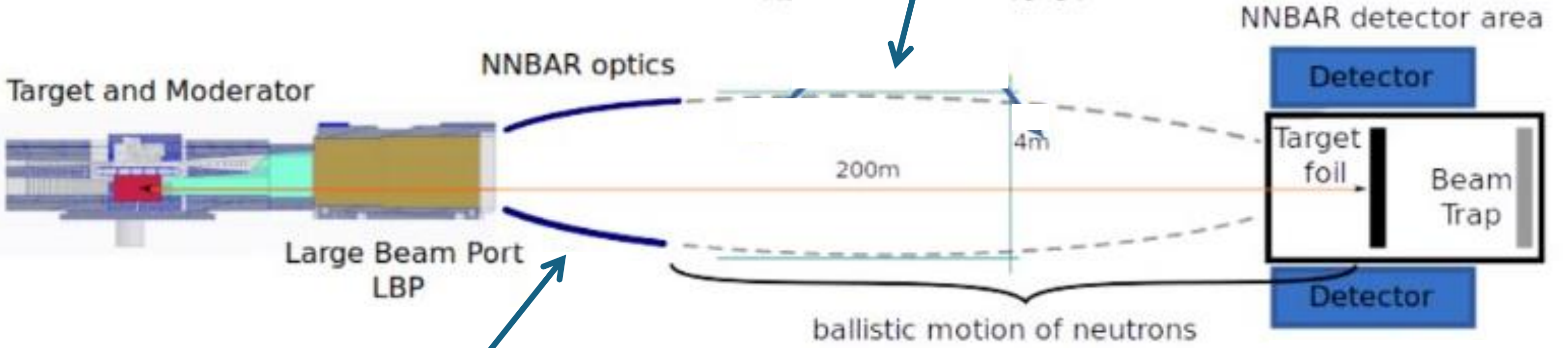
Eg double planar reflector

The NNBAR experiment

Outer and inner octagon-shaped passive shield of 1-2 mm thick sheets of mumetal.



Residual B field <10 nT
Residual vacuum < 10 -5 P



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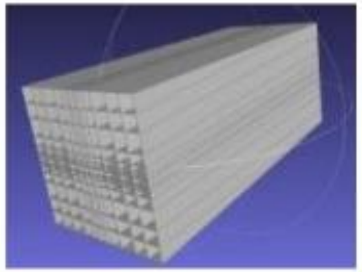

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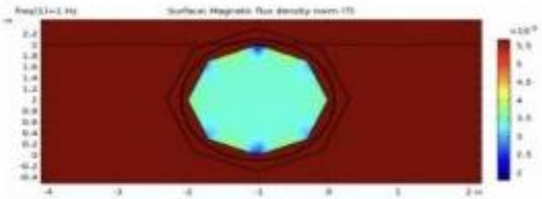

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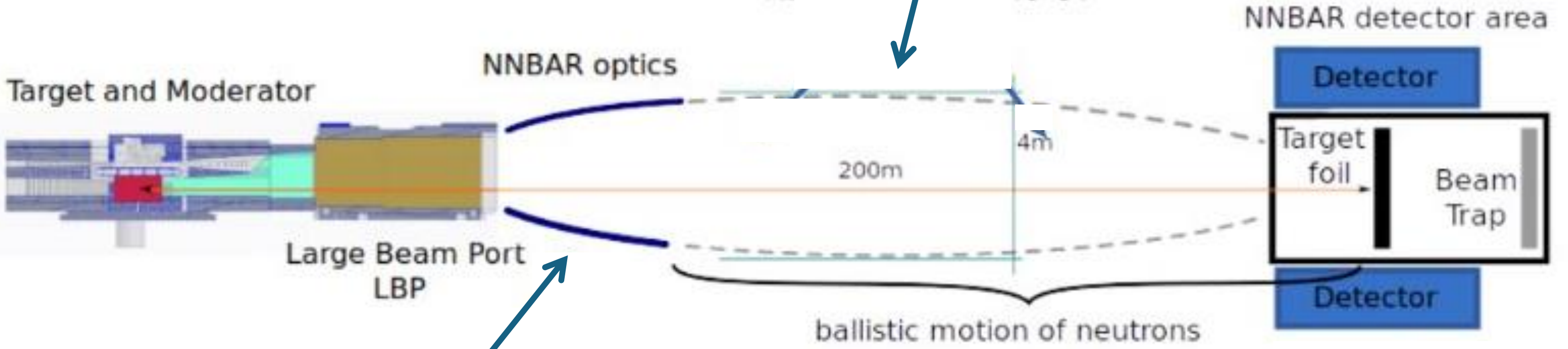

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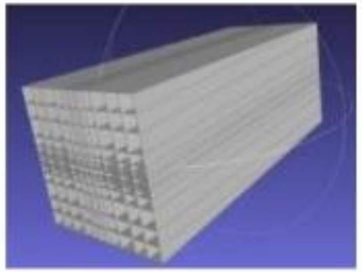

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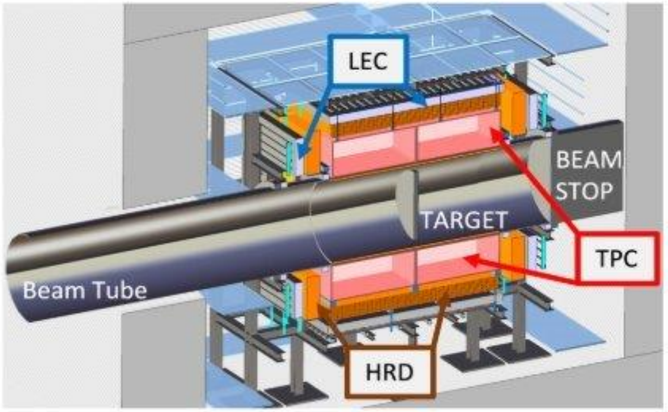
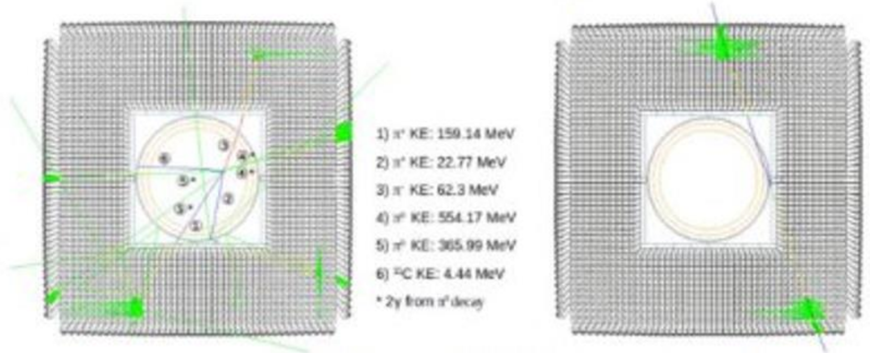


Anti-neutron annihilation detector

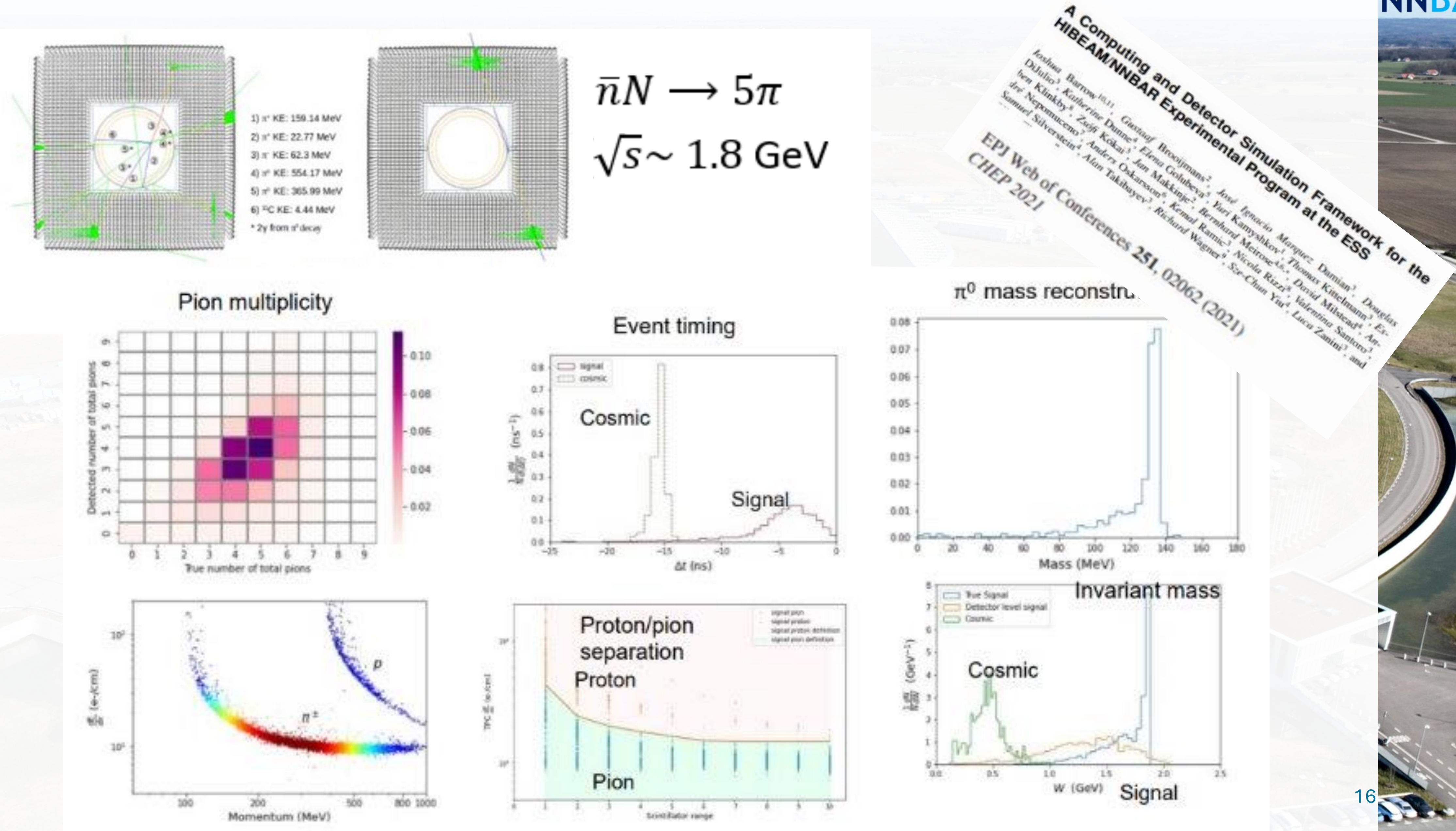


TPC + scintillators and lead-glass

$$\bar{n}N \longrightarrow 5\pi$$

$$\sqrt{s} \sim 1.8 \text{ GeV}$$

Anti-neutron annihilation detector

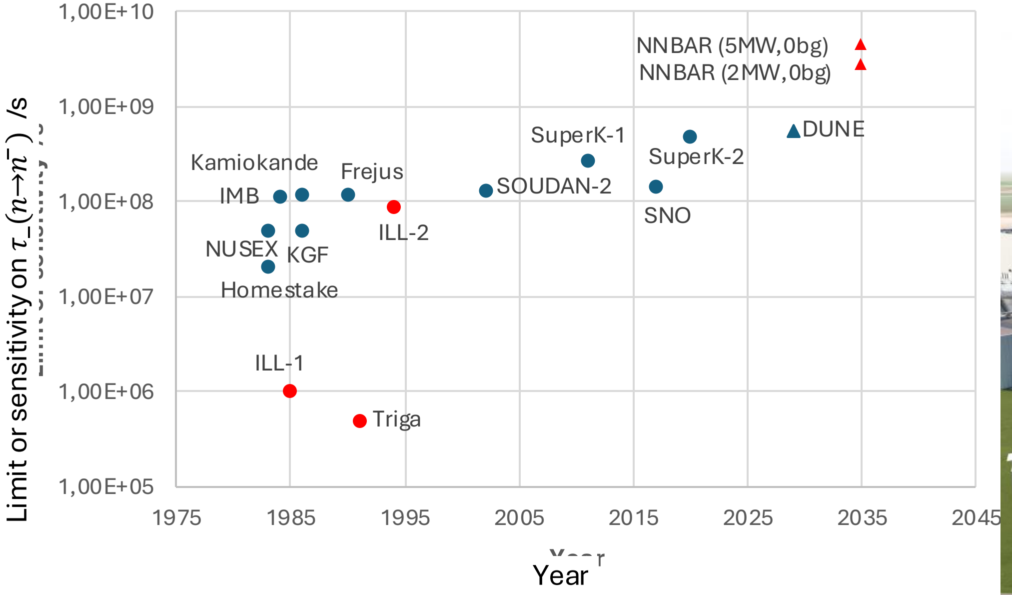


Capability of NNBAR

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

- Zero background experiment
- 1000-fold increase in discovery potential over previous experiments

Selection	Signal	Non-muon background	Muon background
Scintillator energy loss $\in$ [20, 2000] MeV	0.89	0.008	0.3
TPC track cut	0.87	2.3×10^{-3}	9.0×10^{-3}
Pion count $\geqslant 1$	0.82	7.8×10^{-9}	5.9×10^{-4}
Invariant mass $W \geqslant 0.5$ GeV	0.8	7.8×10^{-9}	1.5×10^{-4}
Sphericity $\geqslant 0.2$	0.71	1.8×10^{-11}	7.8×10^{-9}
$E_{\text{scint}, y>0, \text{filtered}} \leqslant 320$ MeV & $E_{\text{scint}, y<0, \text{filtered}} \leqslant 930$ MeV	0.68	-	-

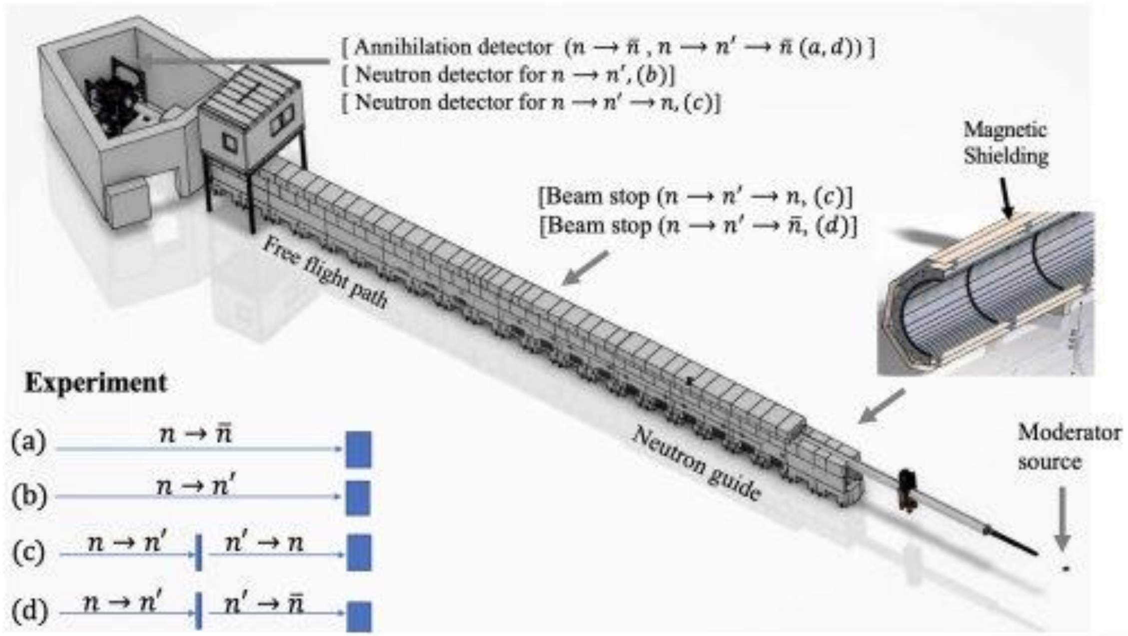


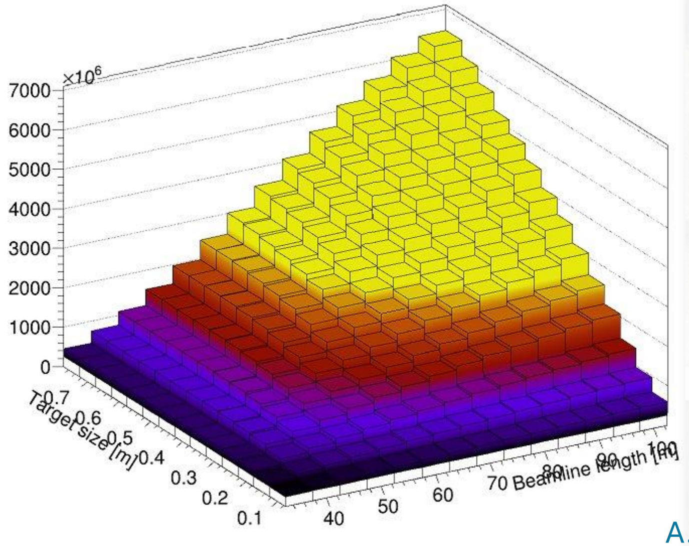
HIBEAM neutron conversion searches

Either:

- Bespoke annihilation detector or
- WASA (CsI) crystal calorimeter

Sensitive to all neutron mixings





×10 improvement

- Neutron to antineutron
- Neutron to sterile neutron

Towards HIBEAM

Swedish Research Council
research infrastructure grant to
Stockholm U, Lund U, Chalmers TU, ESS

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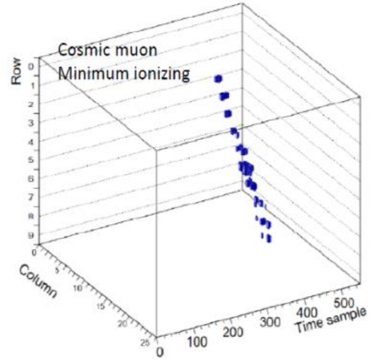
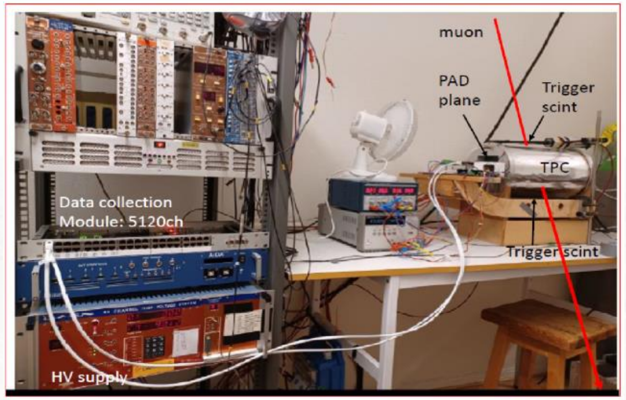
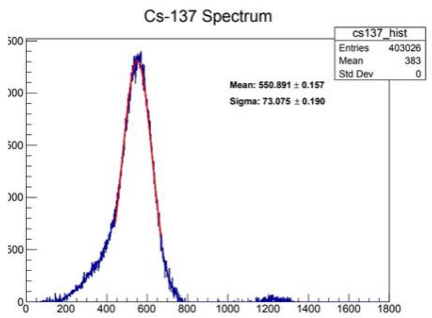
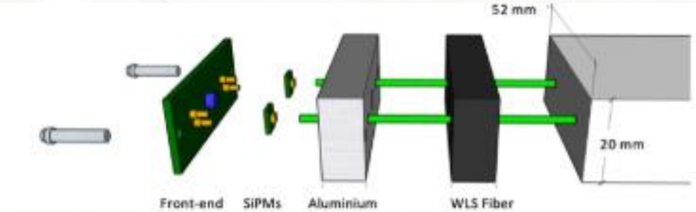
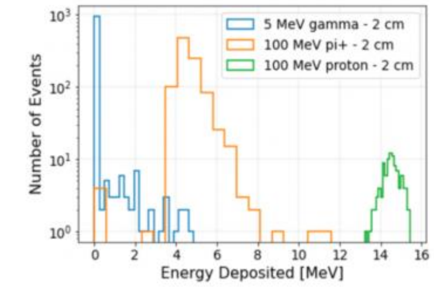
- Prototype development
  - Time projection chamber
  - WASA crystal calorimeter
  - Scintillator/lead-glass calorimeter
- Annihilation detector
- Neutron detector
- Beamline design

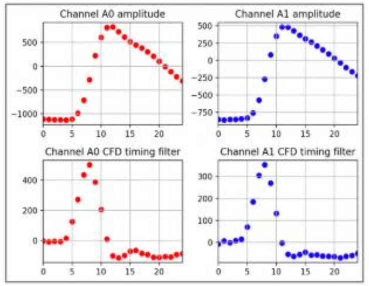






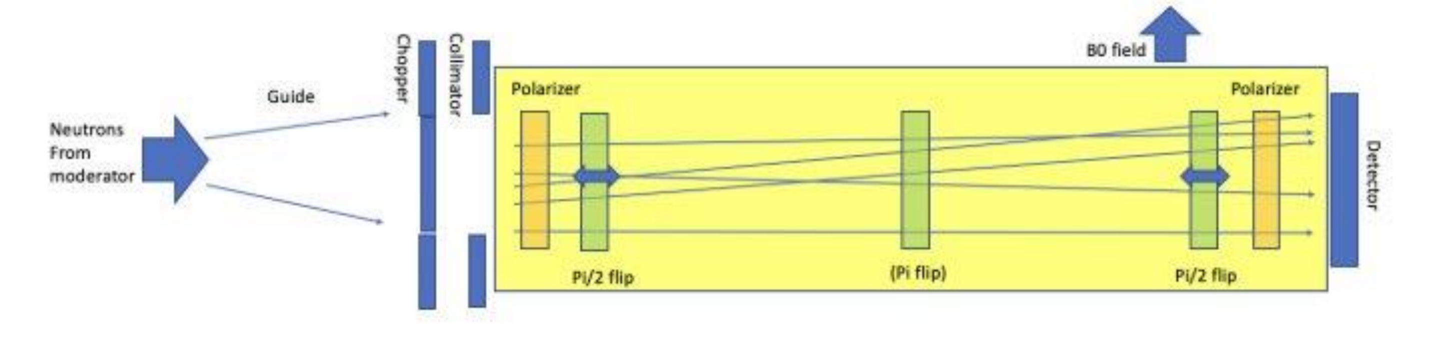




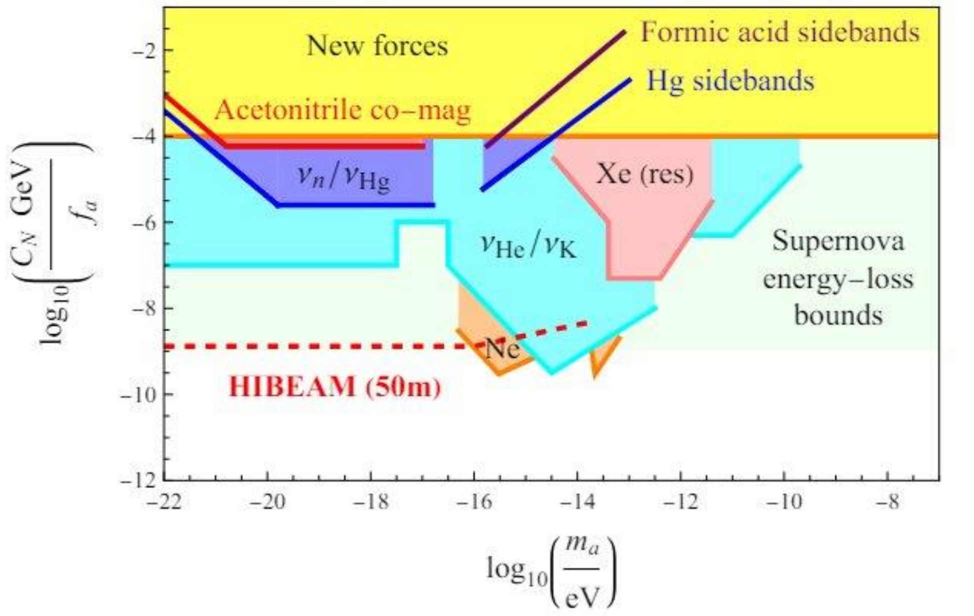


HIBEAM searching for axions

HIBEAM sensitive to axions as a dark matter candidate arXiv:2404.15521



- Ambient axions act as a pseudomagnetic field
- Changes the Larmor frequency (magnetic moment precession)
- Detected through Ramsey interferometry



The HIBEAM/NNBAR collaboration

Co-spokespersons: G. Brooijmans (Columbia U), D. Milstead (Stockholm U)
Lead scientist: Y. Kamyshkov (Tennesee U)
Technical Coordinator: V. Santoro (ESS, Lund U)
Prototype coordinator: M. Holl (ESS)

Many active institutes: SU, CTU, UU, LU (SE), ESS (SE/DK), TUM (DE), Tennessee, Columbia, ORNL (US), Krakow (PL), Rio (BR)...

HIBEAM grants

- Swedish Research Council
- Swedish Foundation for Strategic Research
- Olle Engkvist Foundation
- SRC grant for collaborating with Italian institutes

NNBAR grants

- Part of H2020 grant for ESS upgrade
- STINT award for collaborating with Brazilian institutes

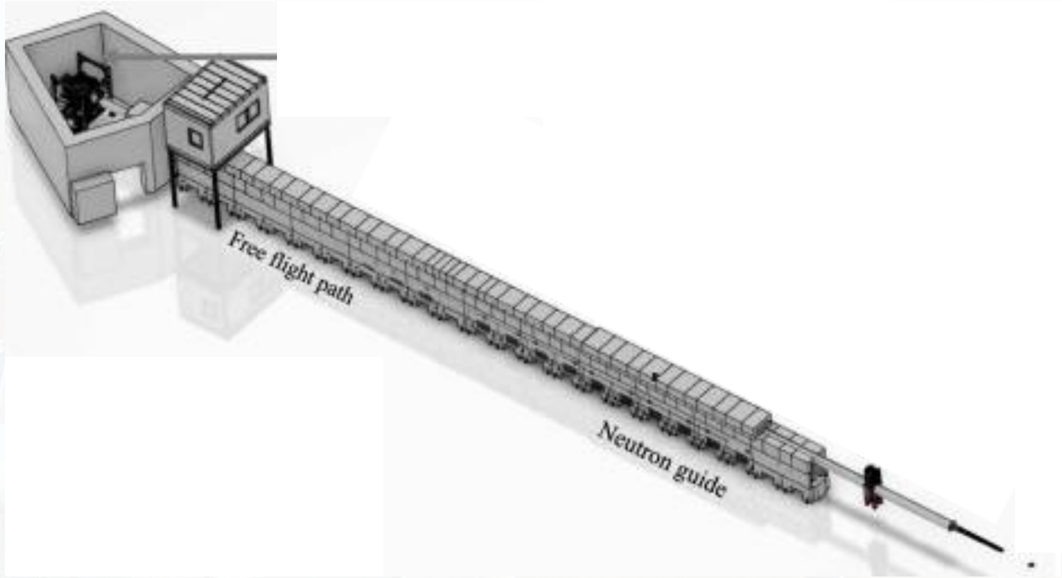
Summary

Neutron oscillations

- Key portal for new physics, rarely explored
- BNV physics – baryogenesis

New discovery window at the ESS

- HIBEAM/NNBAR: a proposed multistage program to increase sensitivity by ~1000
    - o Prototype development
    - o Wide range of applications (neutron/antineutron, neutron/mirror neutron, axions, rare decays etc.)



Thank you

Backup

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