The HIBEAM Experiment at the ESS

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Baryon and lepton number violation

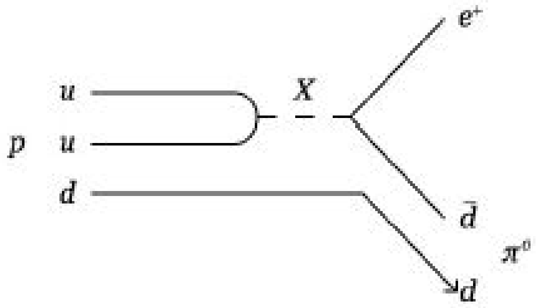
- B, L conservation ↔ accidental symmetries
  - Violation in SM extensions, eg supersymmetry
  - Violation in non-perturbative EW SM (eg spalerons)
- BNV needed for baryogenesis.
  - proton is stable, where is the BNV ?
- Explore selection rules:

$$\Delta B \neq 0, \Delta L = 0, \Delta(B-L) \neq 0 \;\; [n \to \bar{n}, n \to n']$$

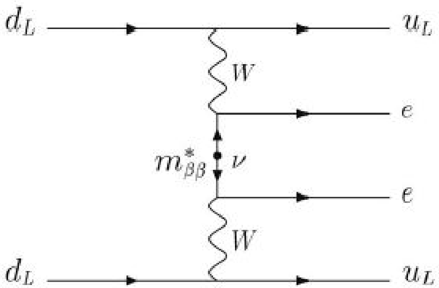
$$\Delta B = 0, \Delta L \neq 0, \Delta(B-L) \neq 0 \;\; [0\nu 2\beta]$$

$$\Delta B \neq 0, \Delta L \neq 0, \Delta(B-L) = 0 \;\; [p\ decay]$$

Complementary BNV, LNV observables

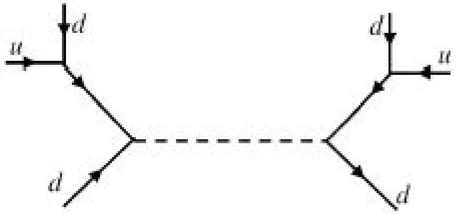


$$p \to e^+ + \pi^0$$
$$\Delta B \neq 0, \Delta L \neq 0$$

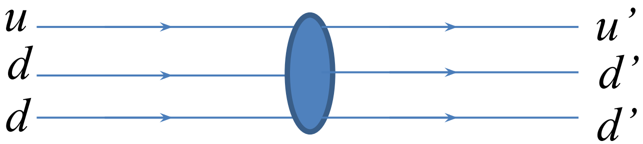


$$0\nu 2\beta$$
$$\Delta B = 0, \Delta L \neq 0$$

Symbiosis

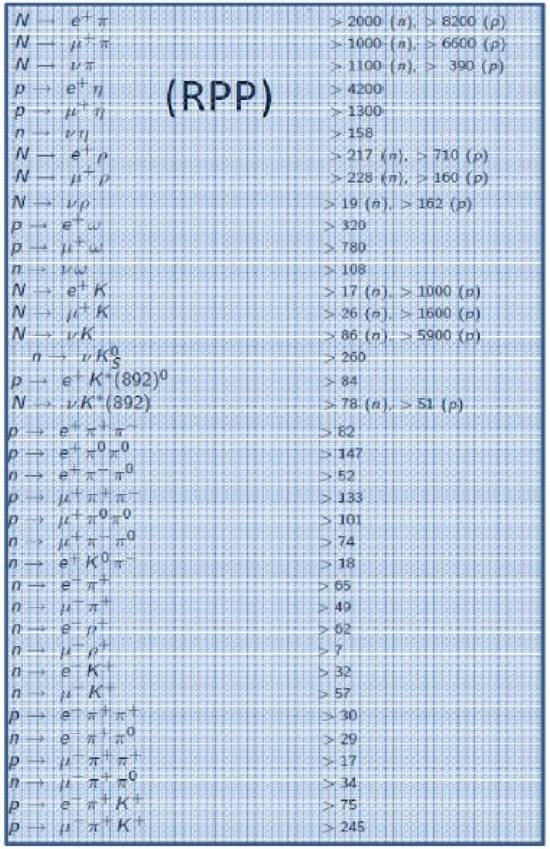


$$n \to \bar{n}$$
$$\Delta B = 2, \Delta L = 0$$



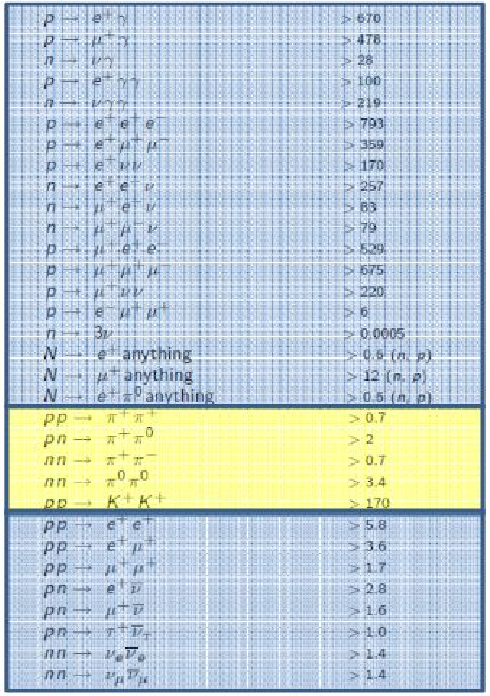
$$n \to n' \text{ (mirror)}$$
$$\Delta B = 1, \Delta L = 0$$

Looking for BNV



(RPP)

Decay mode	Partial mean life (x 10^{30} yrs)
$N \to e^+ \pi$	> 2000 (n), > 8200 (p)
$N \to \mu^+ \pi$	> 1000 (n), > 6600 (p)
$N \to \nu \pi$	> 1100 (n), > 390 (p)
$p \to e^+ \eta$	> 4200
$p \to \mu^+ \eta$	> 1300
$n \to \nu \eta$	> 158
$N \to e^+ \rho$	> 217 (n), > 710 (p)
$N \to \mu^+ \rho$	> 228 (n), > 160 (p)
$N \to \nu \rho$	> 19 (n), > 162 (p)
$p \to e^+ \omega$	> 320
$p \to \mu^+ \omega$	> 780
$n \to \nu \omega$	> 108
$N \to e^+ K$	> 17 (n), > 1000 (p)
$N \to \mu^+ K$	> 26 (n), > 1600 (p)
$N \to \nu K$	> 86 (n), > 5900 (p)
$n \to \nu K^0_S$	> 260
$p \to e^+ K^*(892)^0$	> 84
$N \to \nu K^*(892)$	> 78 (n), > 51 (p)
$p \to e^+ \pi^+ \pi^-$	> 82
$p \to e^+ \pi^0 \pi^0$	> 147
$n \to e^+ \pi^- \pi^0$	> 52
$p \to \mu^+ \pi^+ \pi^-$	> 133
$p \to \mu^+ \pi^0 \pi^0$	> 101
$n \to \mu^+ \pi^- \pi^0$	> 74
$n \to e^+ K^0 \pi^-$	> 18
$n \to e^- \pi^+$	> 65
$n \to \mu^- \pi^+$	> 49
$n \to e^- \rho^+$	> 62
$n \to \mu^- \rho^+$	> 7
$n \to e^- K^+$	> 32
$n \to \mu^- K^+$	> 57
$p \to e^- \pi^+ \pi^+$	> 30
$n \to e^- \pi^+ \pi^0$	> 29
$p \to \mu^- \pi^+ \pi^+$	> 17
$n \to \mu^- \pi^+ \pi^0$	> 34
$p \to e^- \pi^+ K^+$	> 75
$p \to \mu^- \pi^+ K^+$	> 245



$p \to e^+ \gamma$	> 670
$p \to \mu^+ \gamma$	> 478
$n \to \nu \gamma$	> 28
$p \to e^+ \gamma\gamma$	> 100
$n \to \nu \gamma\gamma$	> 219
$p \to e^+ e^+ e^-$	> 793
$p \to e^+ \mu^+ \mu^-$	> 359
$p \to e^+ \nu \nu$	> 170
$n \to e^+ e^- \nu$	> 257
$n \to \mu^+ e^- \nu$	> 83
$n \to \mu^+ \mu^- \nu$	> 79
$p \to \mu^+ e^+ e^-$	> 529
$p \to \mu^+ \mu^+ \mu^-$	> 675
$p \to \mu^+ \nu \nu$	> 220
$p \to e^- \mu^+ \mu^+$	> 6
$n \to 3\nu$	> 0.0005
$N \to e^+$ anything	> 0.6 (n, p)
$N \to \mu^+$ anything	> 12 (n, p)
$N \to e^+ \pi^0$ anything	> 0.6 (n, p)
$pp \to \pi^+ \pi^+$	> 0.7
$pn \to \pi^+ \pi^0$	> 2
$nn \to \pi^+ \pi^-$	> 0.7
$nn \to \pi^0 \pi^0$	> 3.4
$pp \to K^+ K^+$	> 170
$pp \to e^+ e^+$	> 5.8
$pp \to e^+ \mu^+$	> 3.6
$pp \to \mu^+ \mu^+$	> 1.7
$pn \to e^+ \overline{\nu}$	> 2.8
$pn \to \mu^+ \overline{\nu}$	> 1.6
$pn \to \pi^+ \overline{\nu}_\tau$	> 1.0
$nn \to \nu_e \overline{\nu}_e$	> 1.4
$nn \to \nu_\mu \overline{\nu}_\mu$	> 1.4

$\Delta B \neq 0, \Delta L \neq 0$

$\Delta B \neq 0, \Delta L = 0$

Few BNV–only searches

Last search for free $n \to \bar{n}$ in 1990’s.

If nature chooses $\Delta B \neq 0, \Delta L = 0$

→ difficult to observe

→ Baryon decays need a lepton for angular momentum conservation

→ BNV-only observables are fragile:

$n \to \bar{n}$ suppressed for non-free neutrons.

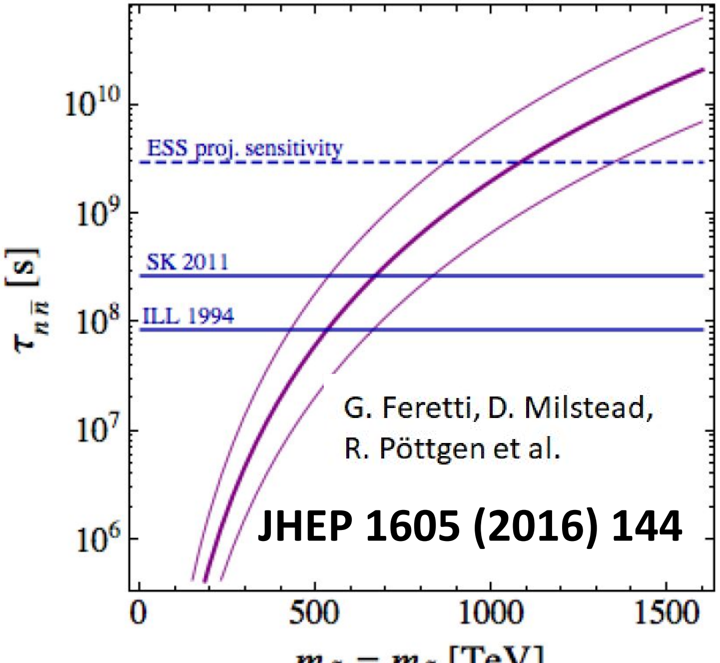
BNV-only observables at HIBEAM

$n \rightarrow \bar{n}\,(\Delta B = 2)$

RPV SUSY , **PeV-scale**

Lepton-quark unification, $0\nu2\beta$
GUT-scale

Post-sphaleron baryogenesis



G. Feretti, D. Milstead,
R. Pöttgen et al.

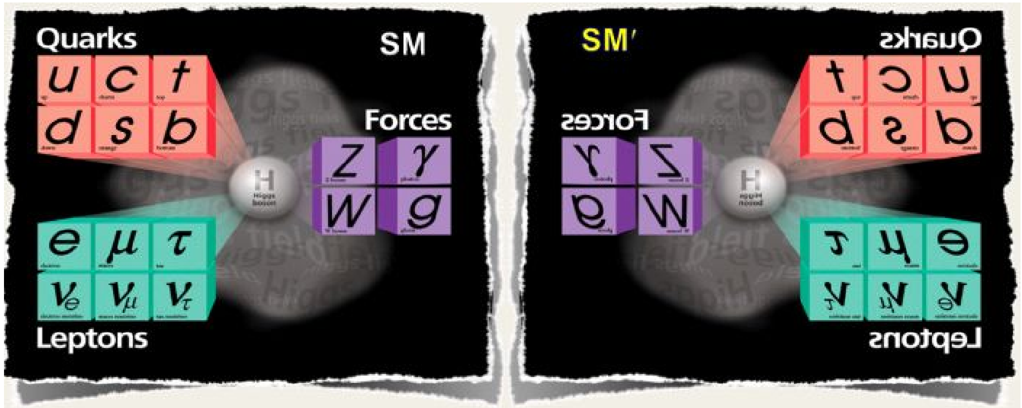
JHEP 1605 (2016) 144

$n \rightarrow n'(\Delta B = 1)$

Mirror matter - parity symmetry, $Q=0$ particles can mix with a ”dark” sector

Dark matter

Resolve neutron lifetime anomaly



European Spallation Source

High intensity spallation source

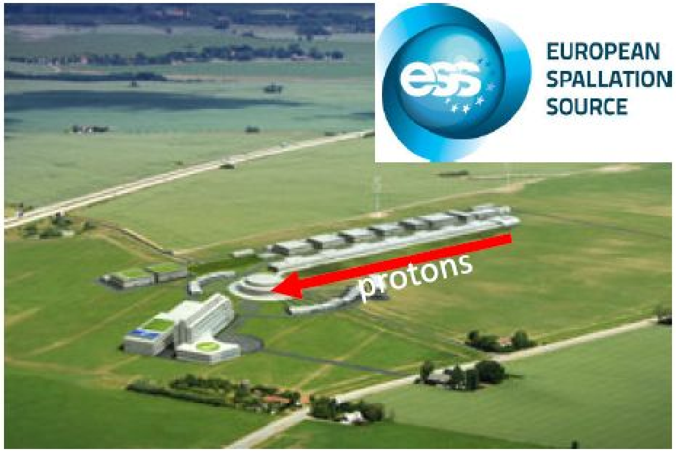
Multi-disciplinary research centre – 17 European nations

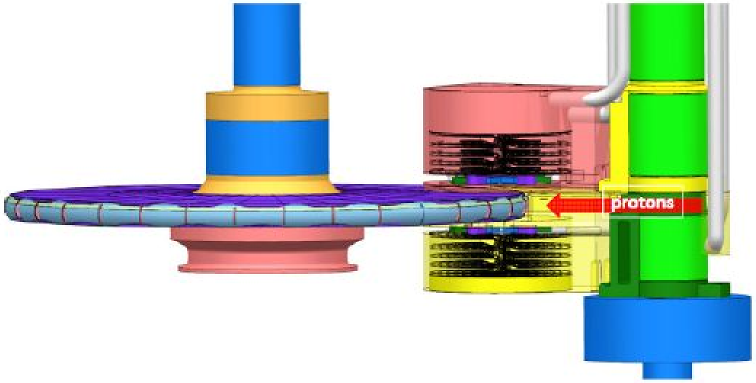
Lund, Sweden

Early physics ~2023/2024

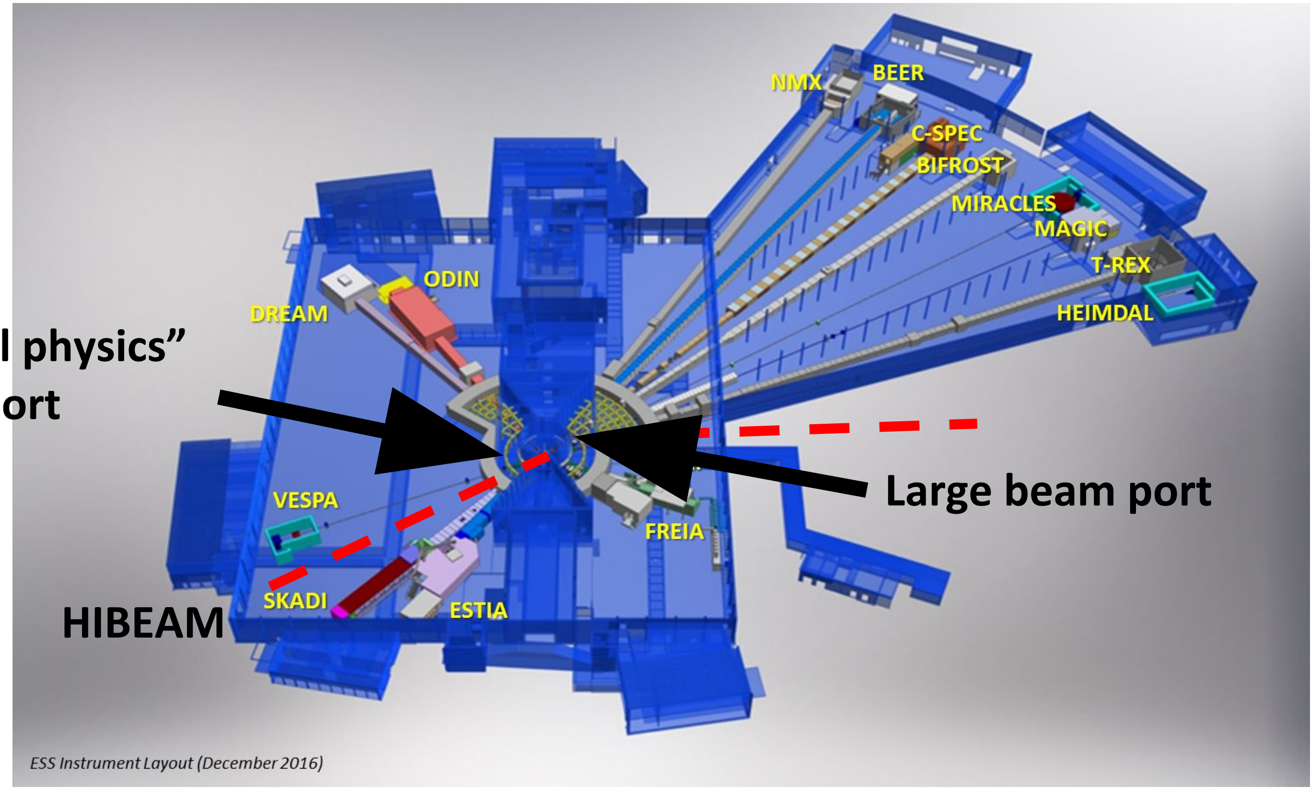
2 GeV protons (3ms long pulse, 14 Hz) on rotating Tungsten target.

Neutrons slowed by moderator and dispatched via beam-ports to expts.





Fundamental physics at the ESS



”Fundamental physics” beam port

Large beam port

HIBEAM

ESS Instrument Layout (December 2016)

Plan for ”fundamental physics” beam port for HIBEAM
Large Beam Port for full expt.

The proposed program

- Stage 1

HIBEAM - high intensity baryon extraction and measurement

Early to late 2020s

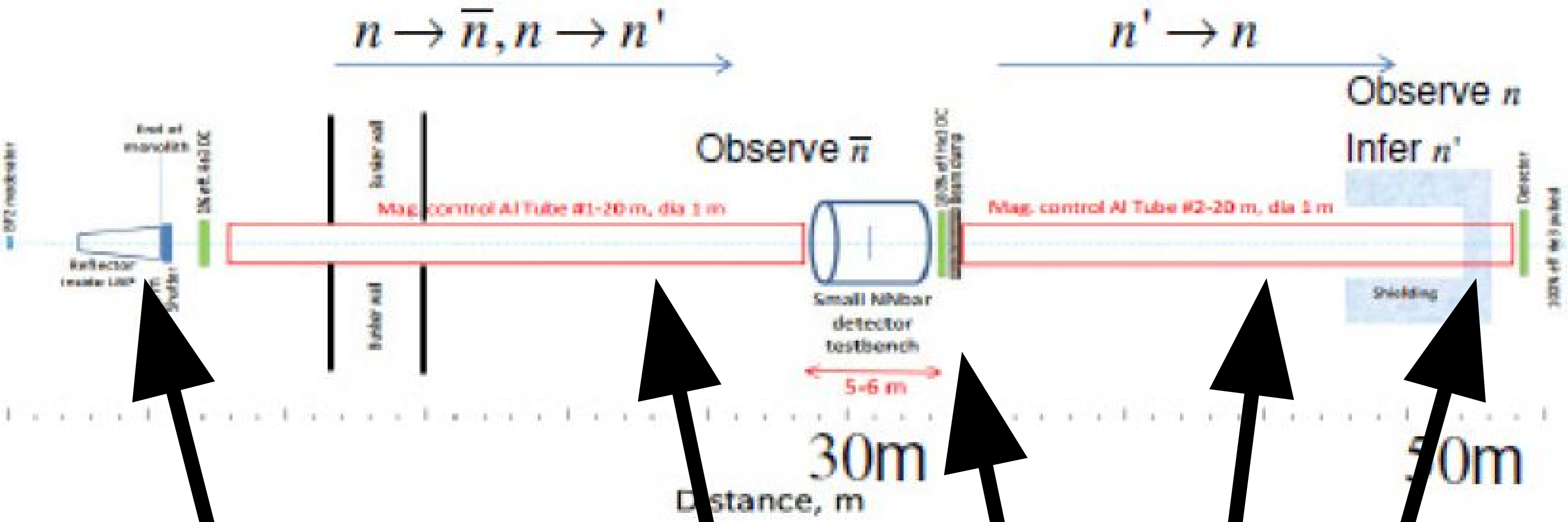
- Match or improve sensitivity to $P(n \rightarrow \bar{n}\ )$ wrt previous search at ILL
- Search for mirror neutrons (regeneration)
- R&D for full experiment (*NNBAR*)

Stage 2

Late 2020’s + 5 years

- Improve sensitivity to $P(n \rightarrow \bar{n}\ )$ by $\sim 10^3$
- Further mirror neutron searches

HIBEAM



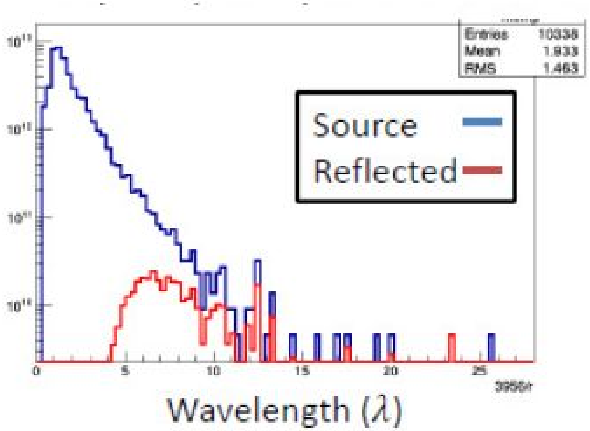
1. Neutron focusing
2. Passage through shielded tube
3. If $n \rightarrow \bar{n} \rightarrow$ annihilation of $\bar{n}$ in C target

4. If $n \rightarrow n' \rightarrow$ passage through absorber
5. $n' \rightarrow n \rightarrow$ measure n in neutron counter

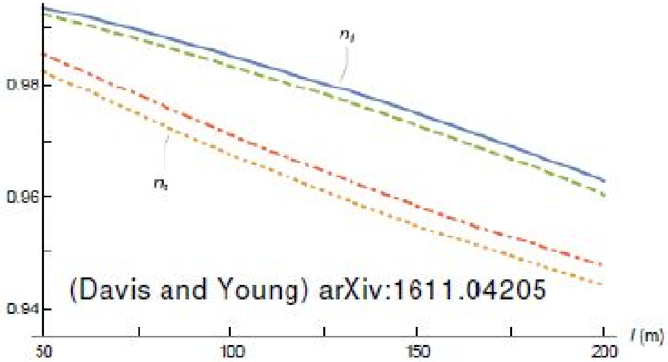
300m long beam tube planned for full NNBAR experiment.

Activities

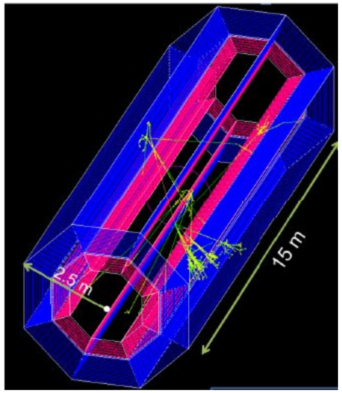
- Neutronics
    - Optics to match moderator

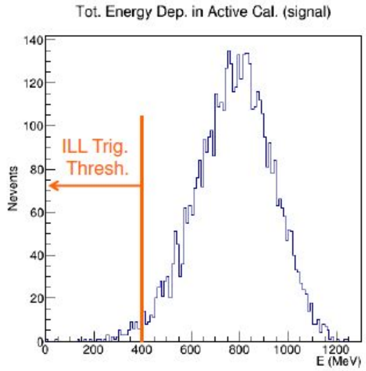


- Radiation Shielding
    - BG suppression
- Magnetic shielding
    - tolerable field (30nT)


(Davis and Young) arXiv:1611.04205

- Detector simulation
    - Tracker,calo + scintillators





HIBEAM and ESS

HIBEAM
Six workshops (CERN, Lund, Gothenburg, Copenhagen)
Expression of Interest 2015.
26 institutes, 8 countries.
Co-spokespersons : G. Broojimans, D. Milstead
Lead scientist: Y. Kamyshkov

Sweden: SU,UU,LU,Chalmers

ESS
No fundamental physics instrument from first call
Wish from ESS management for fundamental physics – new call 2018

Plan to submit a joint proposal with ANNI collaboration in 2018.

Successful application → 10-14 Meuros.

Neutron-Anti-Neutron Oscillations at ESS

Lund, Feb 18-19, 2015

Summary

- Observation of baryon number violation would be of fundamental significance.
- Nature makes BNV-only observables hard to find and measure
  - Last $n \to \bar{n}$ search in 1990’s.
- Unique opportunity for high sensitivity searches for $n \to \bar{n}$, $n \to n'$ at ESS
- HIBEAM is first stage of project to improve sensitivity to $P(n \to \bar{n}\ )$ by $\sim 10^3$.
- Collaboration preparing a proposal for ESS in 2018

- *Follows the European Particle Strategy of supporting a set of experiments with complementary and unique physics reach.*