HIBEAM-NNbar backgrounds

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(On behalf of the HIBEAM-NNbar Collaboration)

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Search for neutron oscillations

- Assumption: baryon number violation (BNV)
- If BNV → nnbar permitted
- How? → Bound or Free nnbar search
- For bound neutrons:
  signal is annihilation of oscillated antineutron with another nucleon.

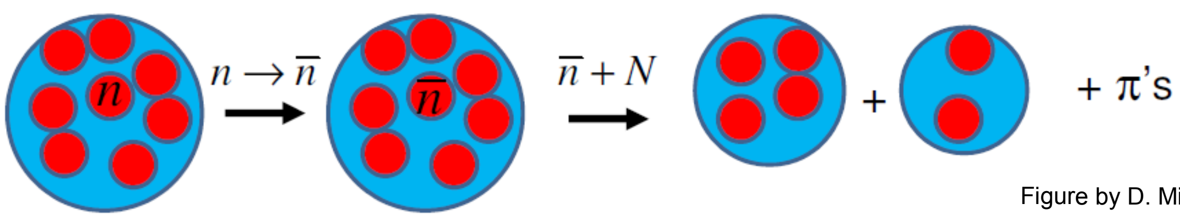


Figure by D. Milstead

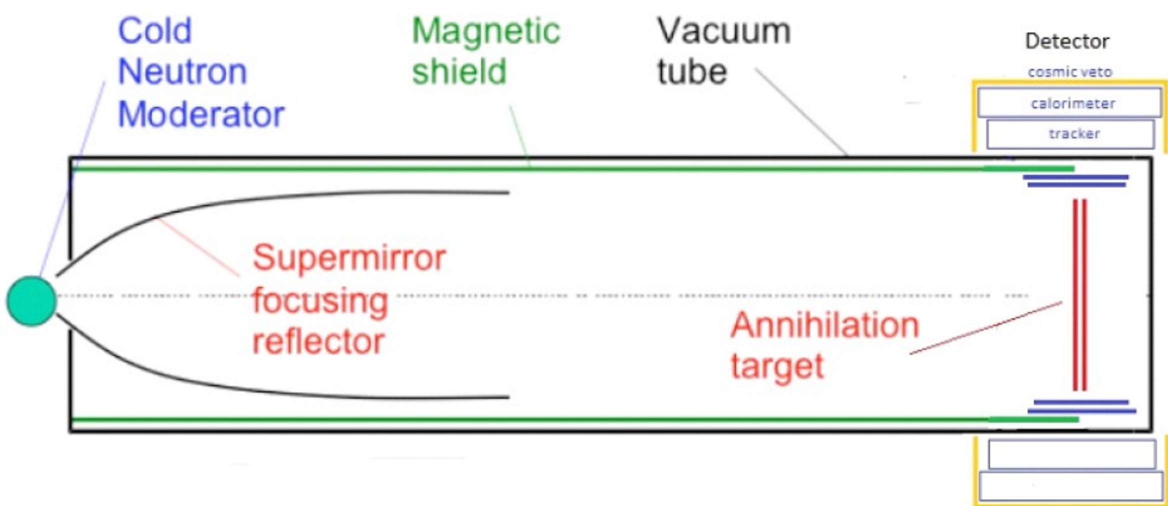
- Rate suppressed by nuclear suppression factor R (~10^{23}) w.r.t free neutrons
- Model dependent

Free NNbar search

- Goal: observe n → nbar (put limits otherwise)
- Strategy: let as many neutrons "fly" for as long as possible
- Probability of free neutron transformation into an antineutron:

$$P(\bar{n},t) = (t/\tau)^2 \qquad \text{FOM} = Nt^2$$

t → neutron flight time; τ → "oscillation time" (BSM predicted, model dependent)



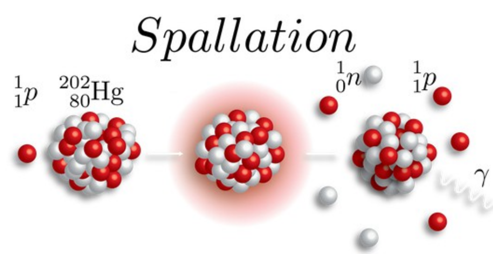
$\tau > 8.7\ 10^7$s (ILL)

L = 30 m (HIBEAM); L = 300 m (NNbar)

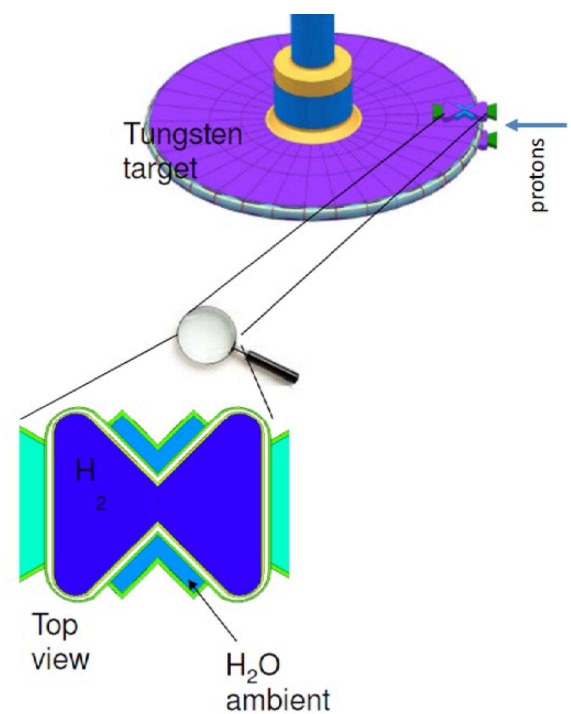
Free NNbar search (cont.)

- Neutrons are bound in nuclei → several MeV for liberation

  → fission
  → spallation (can be kept under full control)



Extract of figure from Mads Ry Vogel Jørgensen, Aarhus University



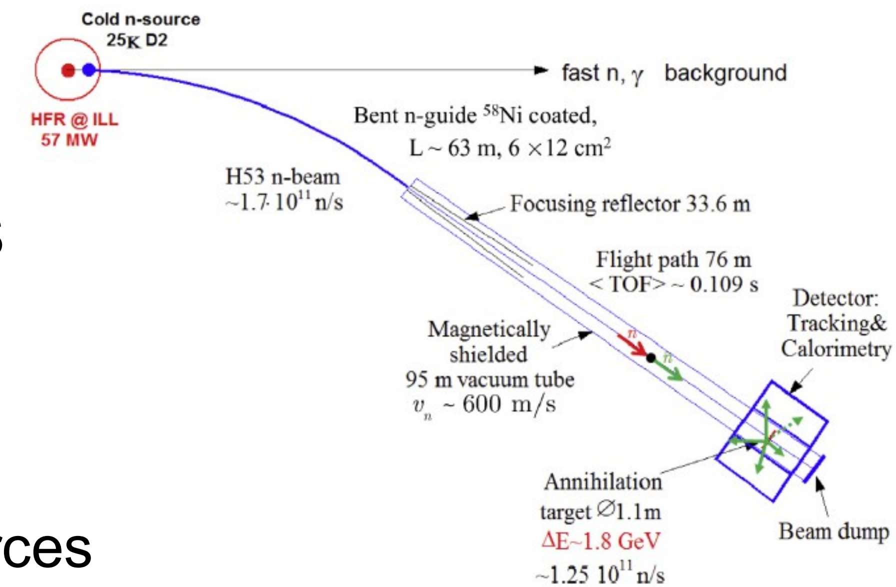
- **To increase *P***:
- *t* large → slow (a.ka. “cold” → few meV)
  need lots of collisions → moderators
- We also want as many neutrons as possible

  →

Background free search?

- Essentially background free search possible
- **→ One event might be a discovery**
- Achieved at ILL
- Zero-background also possible at ESS

- ***But need to***:
- Carefully consider all background sources
- Understand differences w.r.t. ILL
- Shielding design and optimization will influence
- Special for HIBEAM: characteristics of ANNI beam



Configuration of the horizontal $n-\bar{n}$ search experiment at ILL/Grenoble

Antineutron-nucleon annihilation

- Energy release of ~ 2*m_n ~ 1.88 GeV
- Total momentum p = 0
- Distributed over several pions (5 in average): $n + \bar{n} \rightarrow \pi^+ + \pi^- + 3\pi^0$
- Final states extrapolated from antiproton-nucleon:

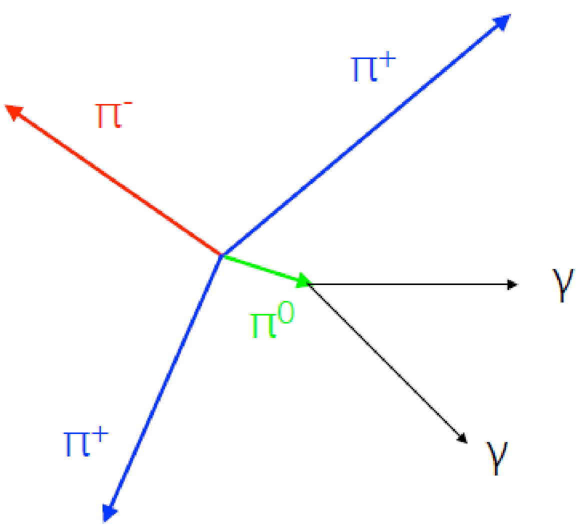
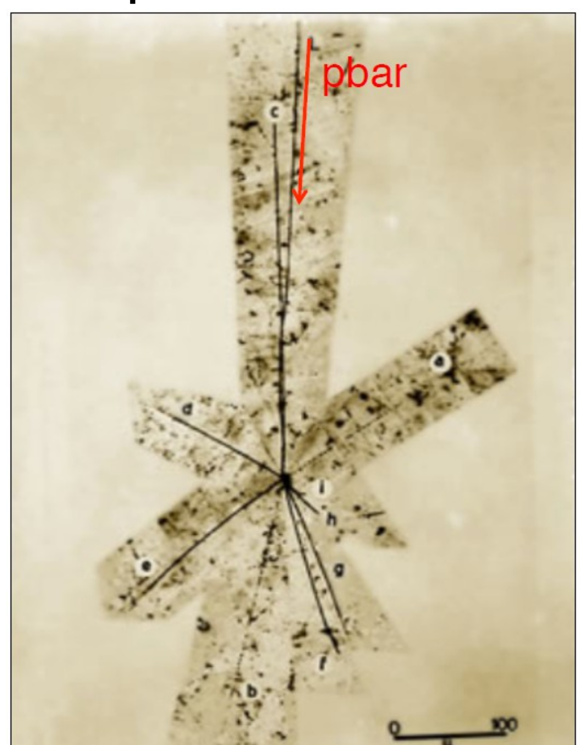


Figure by J. Hewes



Antiproton Star Observed in Emulsion*

O. Chamberlain, W. W. Chupp, G. Goldhaber, E. Segrè, and C. Wiegand, *Radiation Laboratory, Department of Physics, University of California, Berkeley, California*

and

E. Amaldi, G. Baroni, C. Castagnoli, C. Franzinetti, and A. Manfredini, *Istituto di Fisica della Università, Roma Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Italy*

(Received December 16, 1955)

Backgrounds in an NNbar search experiment at a spallation source

- (1) high energy products from the spallation process
- (2) cold neutron beam-generated backgrounds
- (3) cosmic rays

Background source 1: high energy products from the spallation process

- Protons with energy 1–2 GeV interact with a spallation target
- **Backgrounds (NNbar)** → high-energy particles:
- fast neutrons
- protons
- pions
- muons
- gammas
- → ***background was not present at ILL***

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Background source 1: high energy products from the spallation process (cont.)

- Timely correlated with proton beam pulse on tungsten
  (pulse width = 3.5 ms, 14 Hz repetition rate)
- Can be suppressed: detector dead time for these time regions
- OK as flux of slow neutrons is ~ continuous in time
- ~ 5% of the beam intensity is loss
- **Does not apply to HIBEAM-ANNI**
  → curved guide → only cold neutrons pass through!

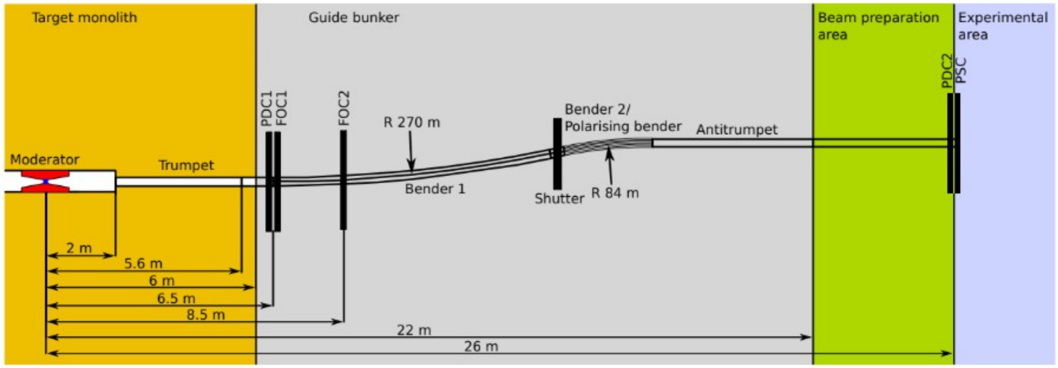
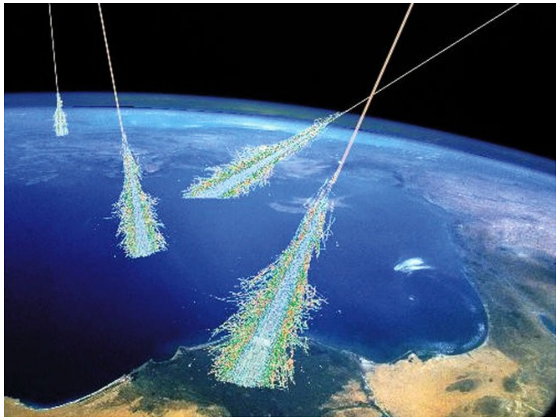


Figure 1. Side view of the ANNI beam line (schematic). The vertical scale is stretched by a factor of 4 for better readability. See text and tables 1 and 2 for details.

Background source 2: Cosmic Rays (CR)



- Dominant background
- For NNbar at ILL , trigger rate = 4Hz → 3 Hz CR
- 2.7 Hz → CR muons ; 0.3 Hz → neutral CR
- **Neutral CRs → evade CR veto!**
- Fake signal events originating from the target and beam tube
- Leading contributor to background in the signal window.

- NNBar/HIBEAM → larger annihilation target area
  → larger detector volume
  → improve vertex reconstruction & event identification

Background source 3: cold neutron beam backgrounds

- Flux: $10^{12} - 10^{13}$ neutrons per second
- Neutrons → captured by target
  stopped at beam dump

- Neutron capture in the annihilation target → MeV gammas
- Not "track-like background" but influence trigger!
  (E_{gammas} > $trigger_{threshold}$)

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- ILL: beam dump made of ^{6}Li (emits no gammas!)

- Higher neutron flux HIBEAM-NNbar →
  shielding, detector granularity, tracking resolution, trigger cuts

Other backgrounds: free neutron decay background

- Free neutrons unstable (mean life ~ 14.6 minutes)
- At 10^{13} neutrons/s ~ 10^8 neutrons will decay within length of detector

$$n \rightarrow p + e^- + \bar{\nu}_e$$

(protons ~ low energy → stopped in the walls of the beam tube)

- Electrons → background
- If neutron decays inside tracker → can spoil charged pion vertex reconstruction

→ need excellent tracking resolution!

Background estimation and suppression strategies

Background estimation

2 methods:

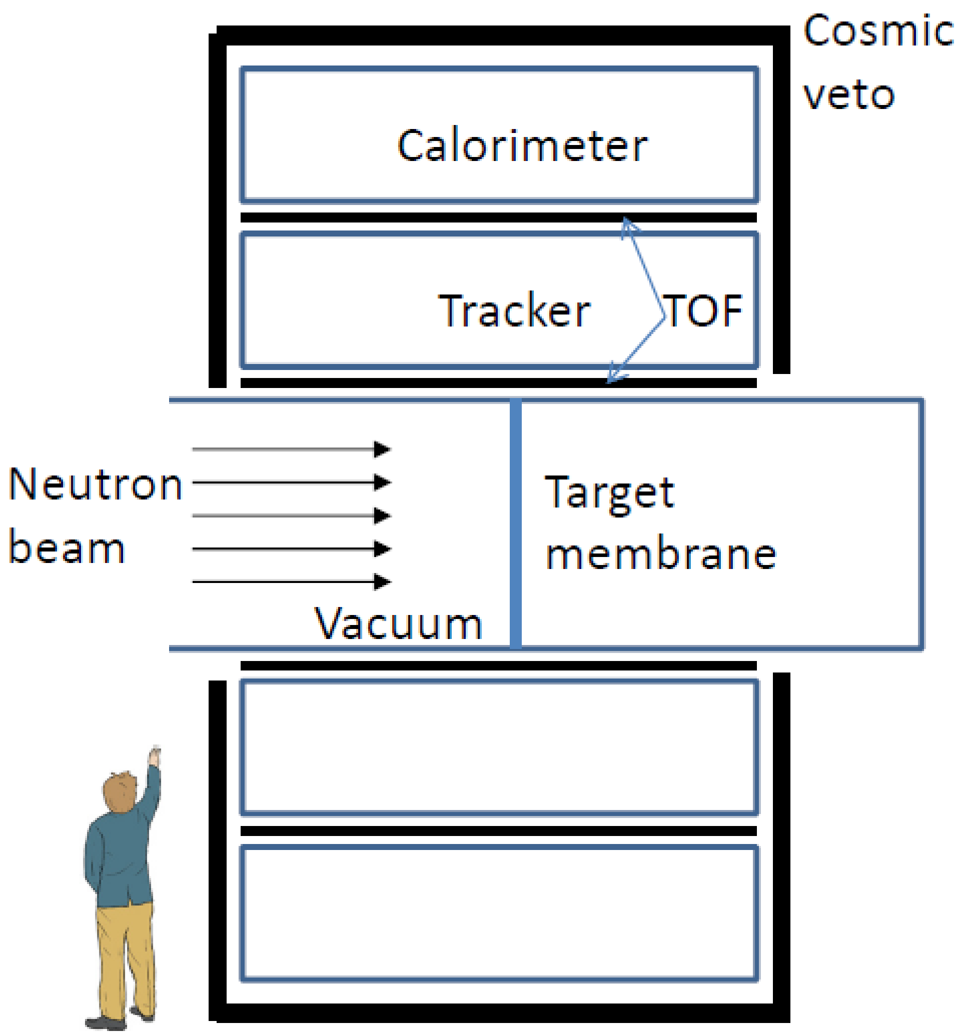
- "Switch off" magnetic shielding → suppress the n-nbar oscillation effect → background-only events
- Add more targets downstream annihilation target → produce "sources" for background events without annihilation signal

→ ***Identify false positives***

- Combine above with parameterization of background cuts → estimate background in signal region

Detector

Antineutron detector - zero-background



charged pions → tracking detector (e.g. time projection chamber)
neutral pions → electromagnetic calorimeters

Annihilation Detector

- (i) annihilation target and detector vacuum region;
- (ii) tracker;
- (iii) time of flight systems;
- (iv) calorimeter;
- (v) cosmic veto system;

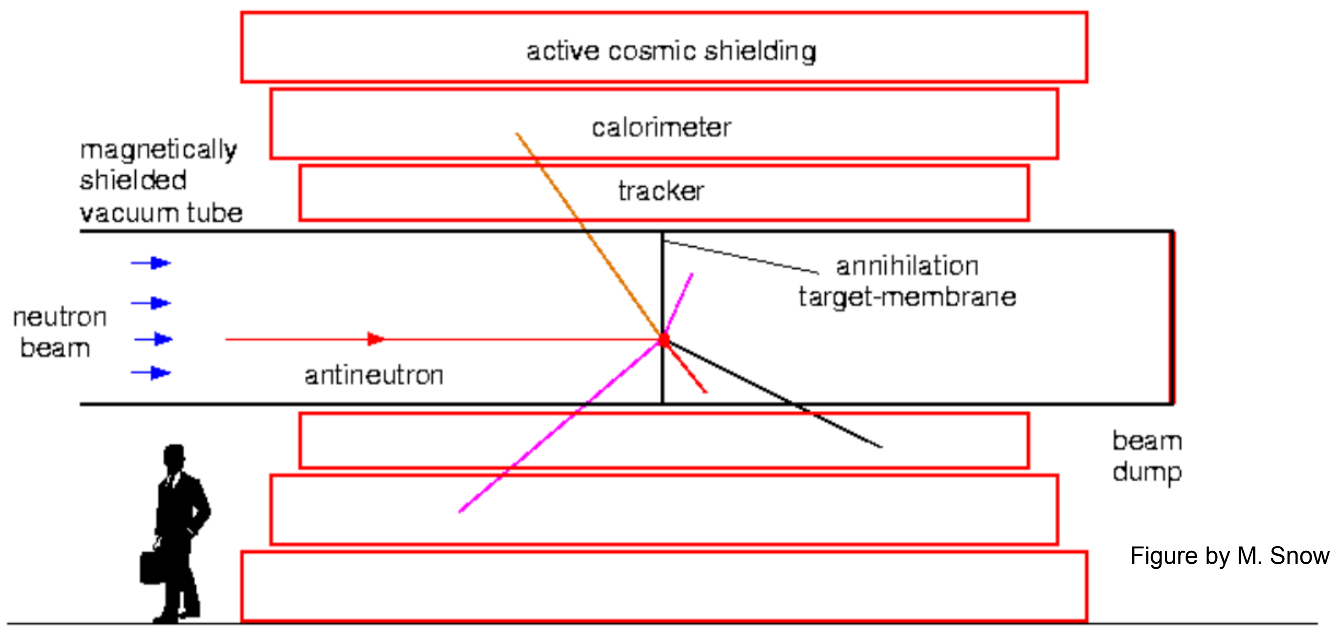
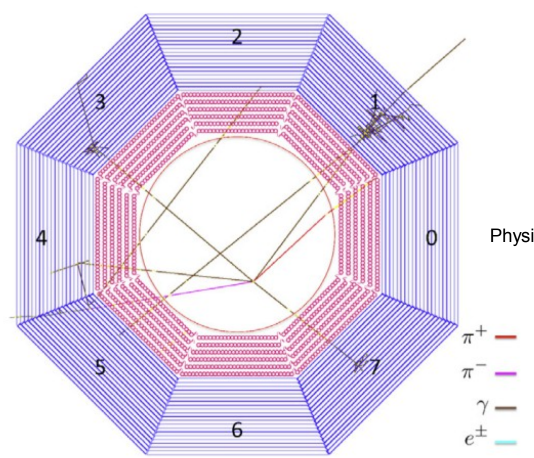


Figure by M. Snow

Tracker

- Tracking capability of the annihilation detector
  → critical tool for background rejection
- Candidate pions comes from a single vertex
- Position of annihilation vertex with high accuracy
  → check momentum balance + inv. mass reconstruction!
- Relevant tracker technologies: straw tubes (e.g. ATLAS TRT), proportional and drift detectors

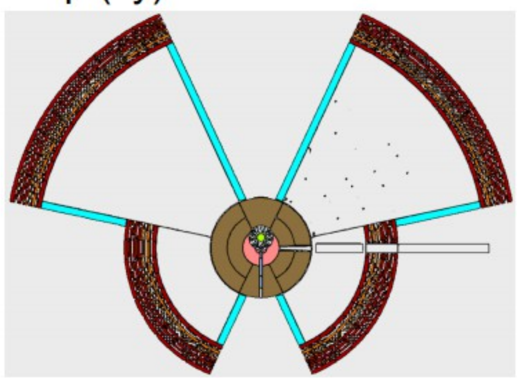


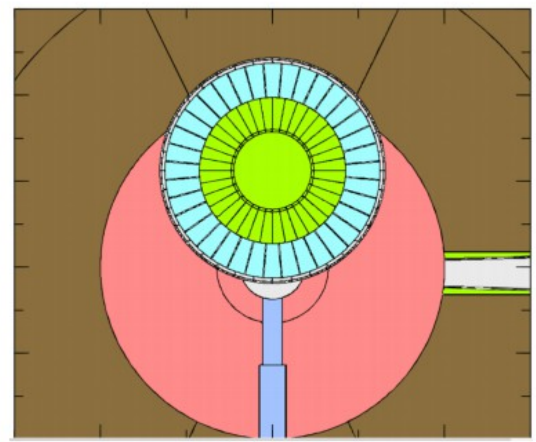
Physics Reports, Volume 612, 11 February 2016, Pages 1-45 (FERMILAB-PUB-14-263-T)

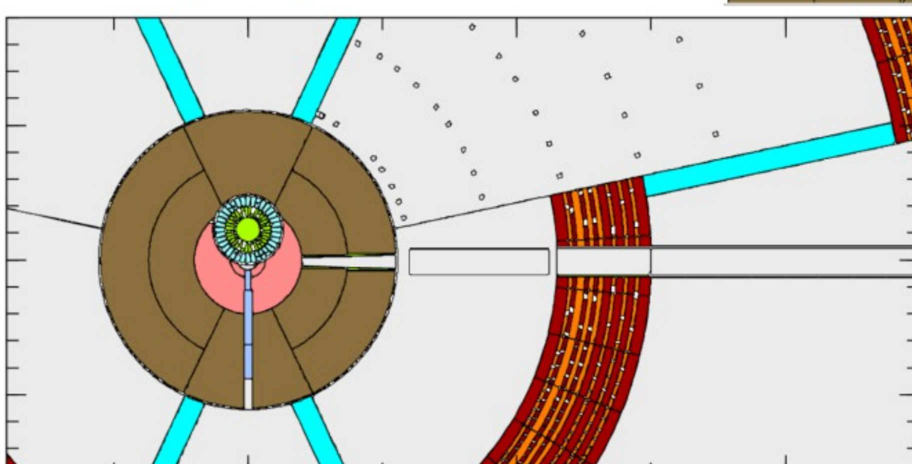
HIBEAM shielding: status

- Shielding optimization: important component of S/B estimation
  → influences detector design
- (preliminary) HIBEAM model implemented in PHITS
- Working to implement HIBEAM geometry running from ANNI

Top (xy) view







Summary

- Neutron-antineutron experiment at ESS possible
- Backgrounds of the experiment are low and can be kept under control – in particular pulsed nature of ESS proton beam can be explored
- For HIBEAM using the ANNI beam high energy backgrounds are not a concern
- Essentially background-free search is possible
- Work is under way to implement new simulations
- Collaboration with ANNI desirable

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Backup