HIBEAM at the ESS - status and plans

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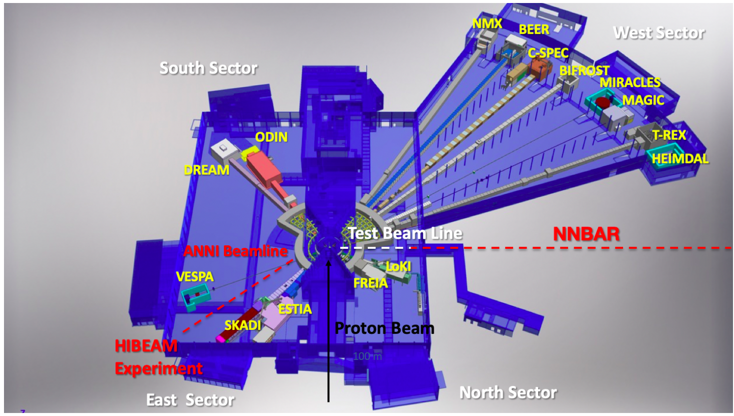
https://nnbar.eu/

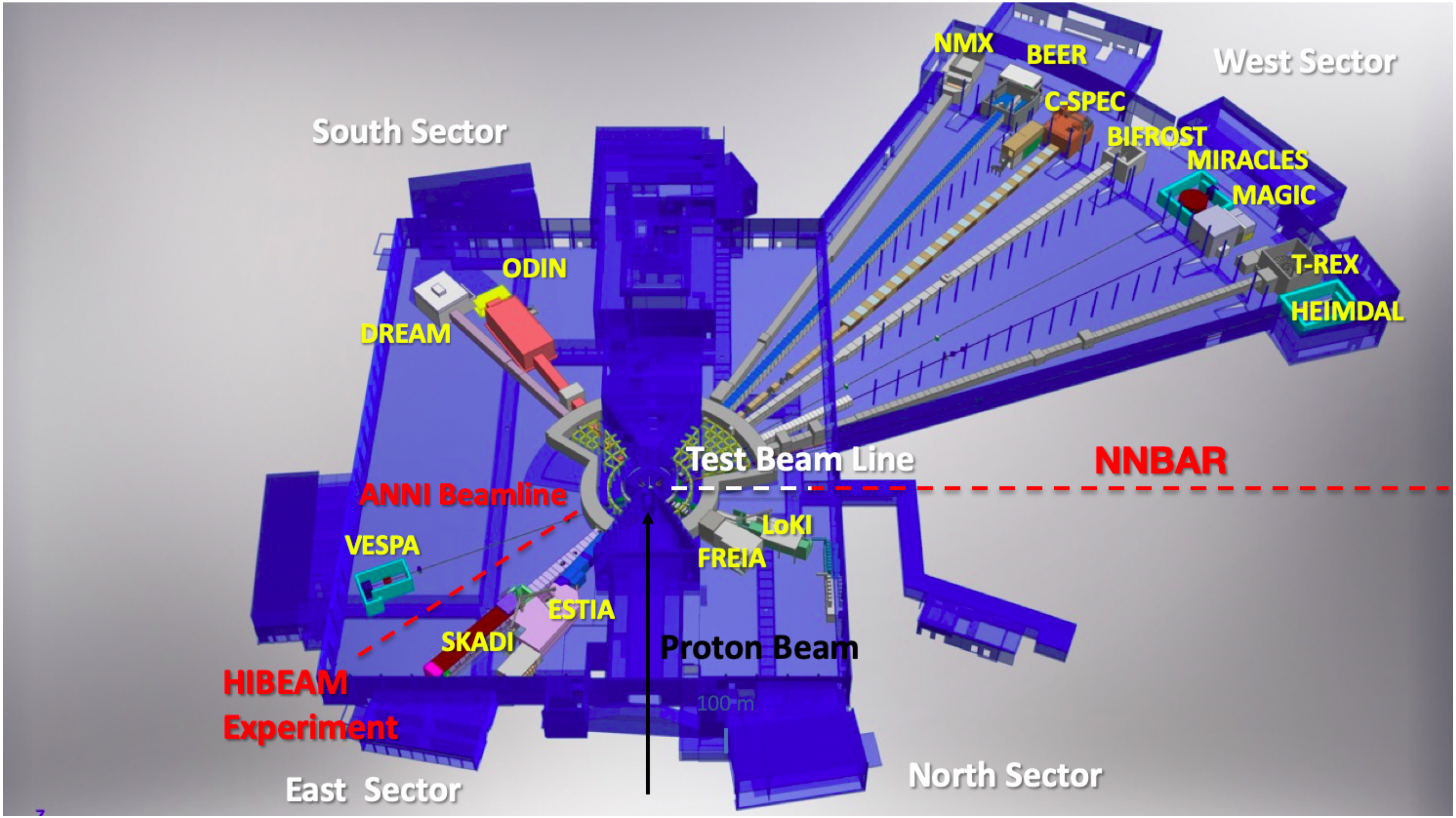
HIBEAM and NNBAR

- Staged experiment
- 1. HIBEAM (High Intensity Baryon Extraction and Measurement)
  - late 2020's
  - world leading searches $n \rightarrow n'$
  - search for $n \rightarrow \bar{n}$ (with lower sensitivity)
  - also search for $n \rightarrow \bar{n}$ via sterile neutrons. *First such search*.
  - R&D for NNBAR.

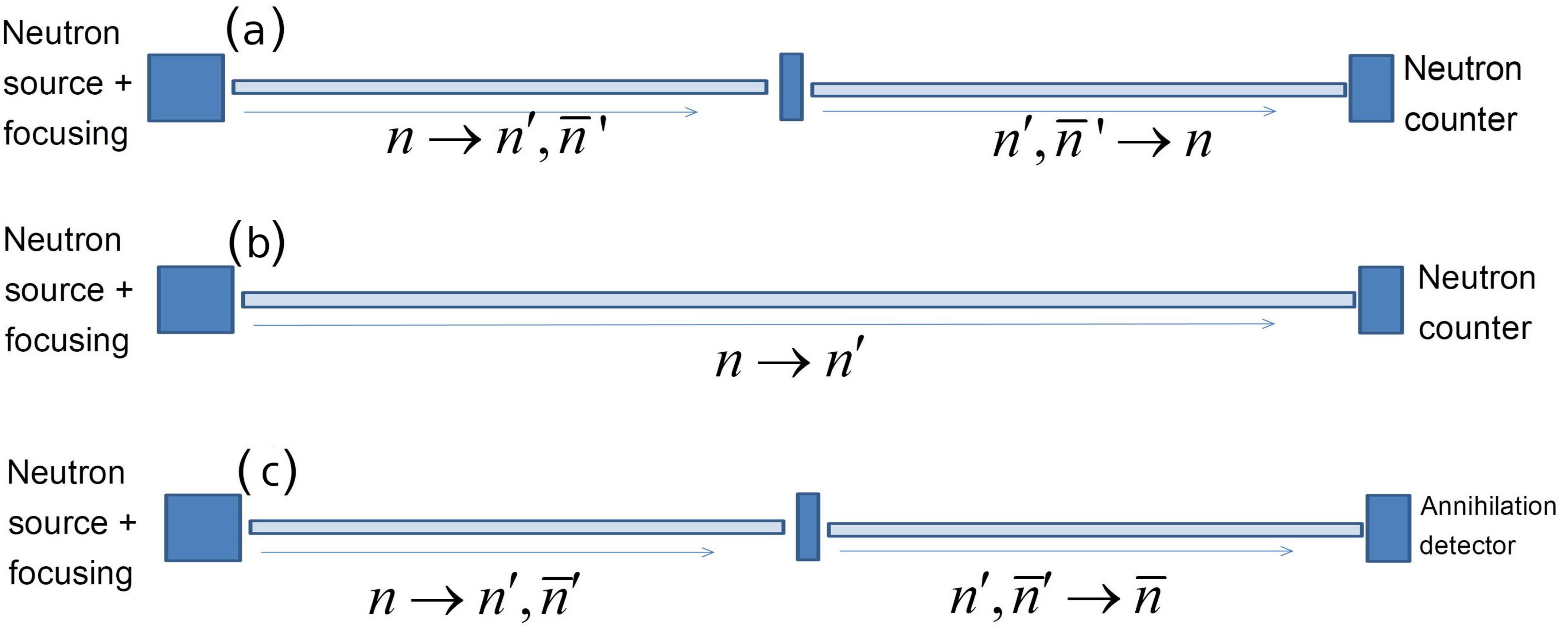
- 2. NNBAR
  - extremely high precision searches $n \rightarrow \bar{n}$, $n \rightarrow n'$
  - improve sensitivity to oscillation probability by ~ 10^3
  - After 2030



- Prototype/bg tests (cosmic rays) could start as early as 2023


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

HIBEAM searches



Why HIBEAM?

- First stage of NNBAR
- But far from being only that!
- **HIBEAM is a world leading experiment on its own right**
- Explores selection rules $\Delta B = 1, 2$
- Potential to cover vast parameter space in sterile neutron searches

Discovery sensitivity

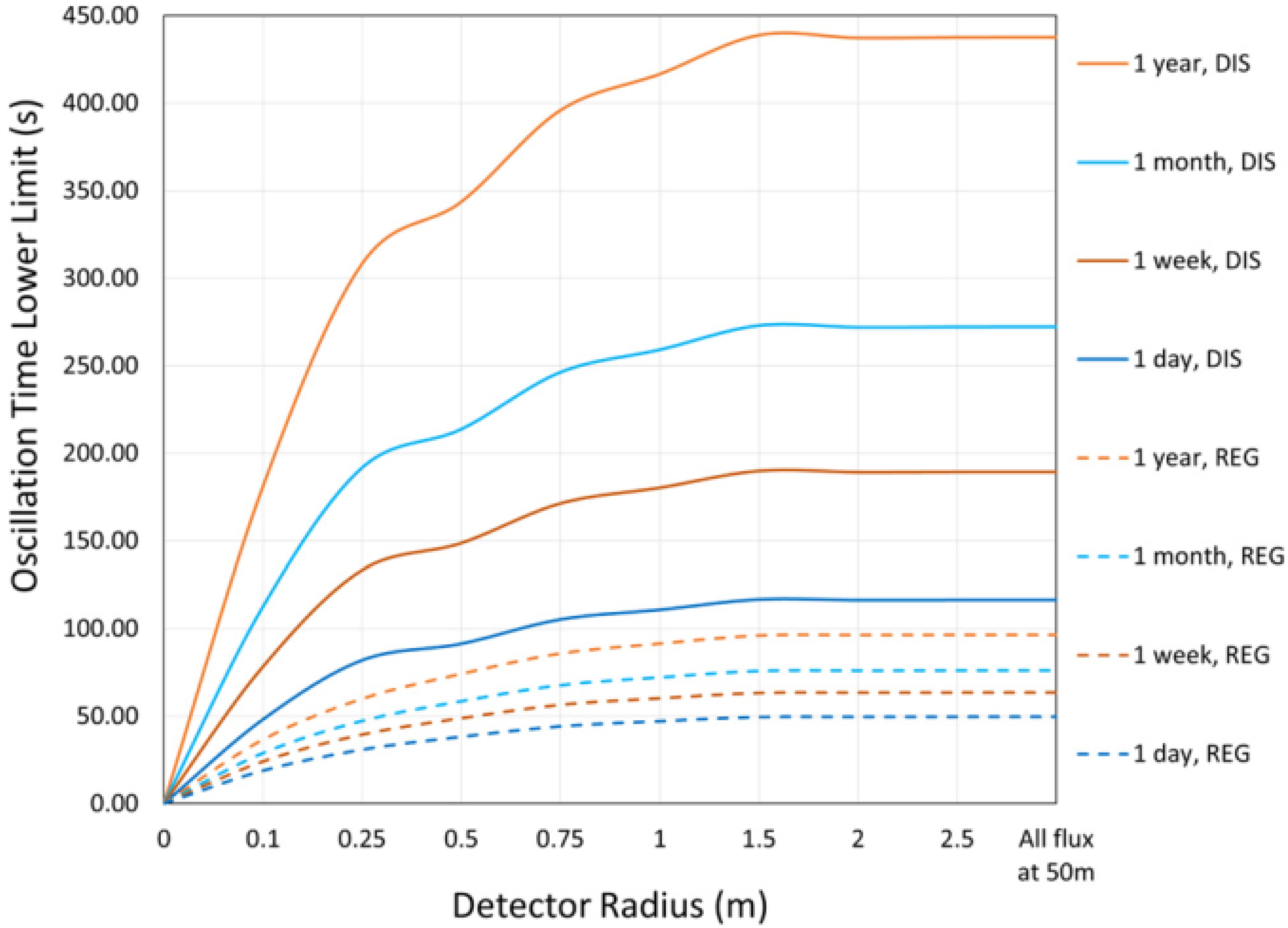


Figure 21. Sensitivity at 95% CL for the discovery of $\tau^{\mathrm{dis}}_{n\to n'}$ (disappearance, 'dis') and $\tau^{\mathrm{reg}}_{n\to n'}$ (regeneration, 'reg') for various detector radii for the nominal 1 MW HIBEAM/ANNI flux at 50 m. A background rate of 1 n s^{-1} is assumed for the regeneration search. Plots have been smoothed.

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VR RFI Grant

- HIBEAM pre-studies - research needed ahead of a formal beamline proposal (grant coordinator: D. Milstead)
- 10 MSEK (2022-2023) from VR
- Complete CDR by 2023
- Project divided in 4 Work packages
- W1: Beamline simulation (coord: V. Santoro (ESS))
- WP2: Annihilation detector design (coord: BM (SU and LU))
- WP3: Annihilation detector prototype/components R&D and tests (coordinators: S. Silverstein (SU) and A. Kupsc (Uppsala))
- WP4: Neutron detectors (coordinator H. Perrey (LU) Y. Kashmikov (Tennessee)

Different paths of HIBEAM

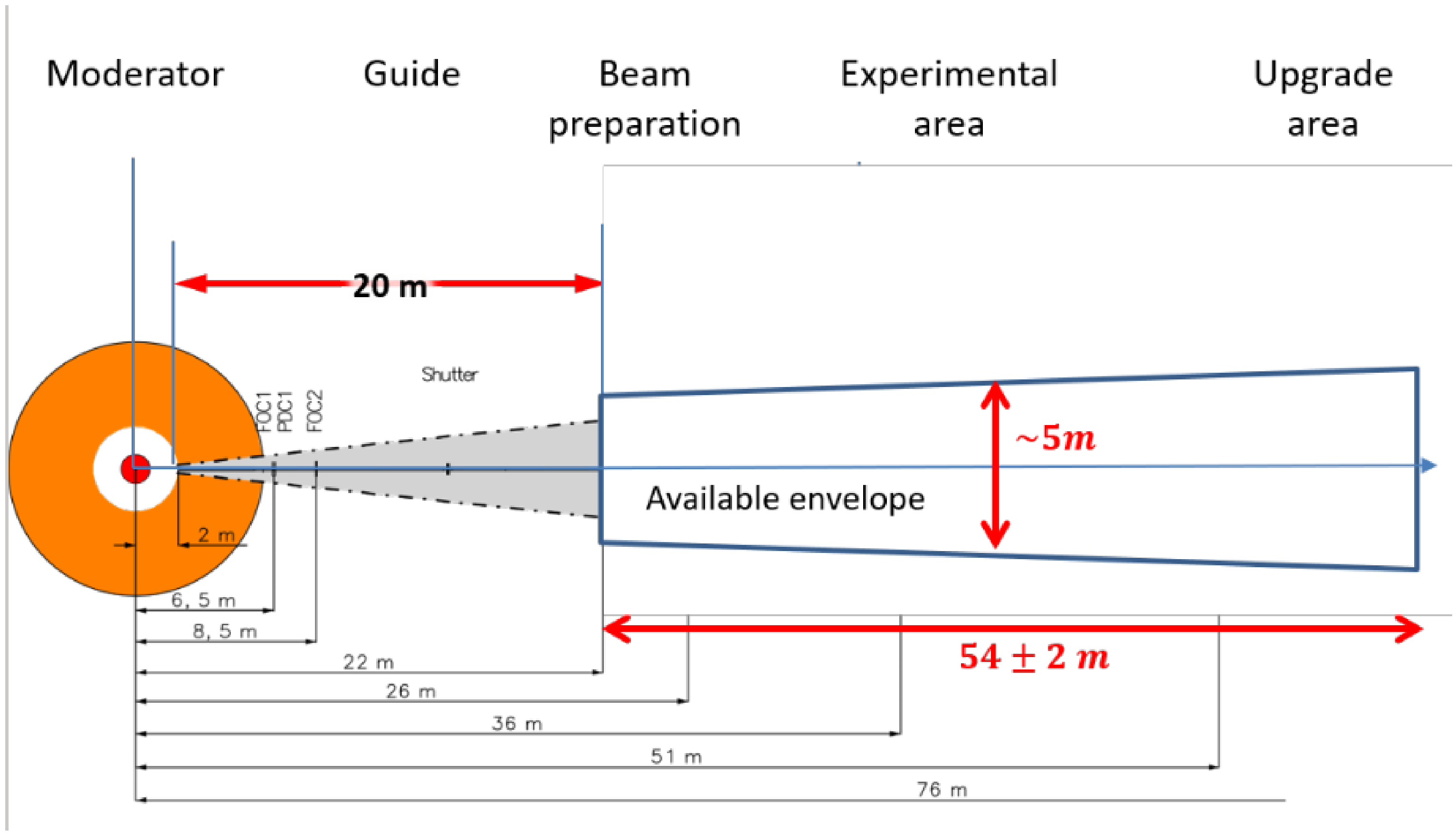
- HIBEAM in exploratory/study phase.
- RFI grant provides funding for best solution to be found – time scale (end of 2023).
- The goal is to find the optimal solution taking into account cost, scientific potential and timing (including possible shifts in ESS schedule).
- Different detector scenarios take into account cost, but also different beamline scenarios.
- Also significant is the potential to use the HIBEAM as R&D for NNBAR.

WP1: Beamline design
(coordinator: V. Santoro)

WP1 summary (beamline simulations)

- **Three main goals:**
- Design of HIBEAM at ANNI
- Design HIBEAM at TBL
- Design of magnetics

HIBEAM@ANNI



ANNI: possible fundamental physics beamline (FPB) at ESS
Uses curved guide: only cold (slow/meV) neutrons get trough

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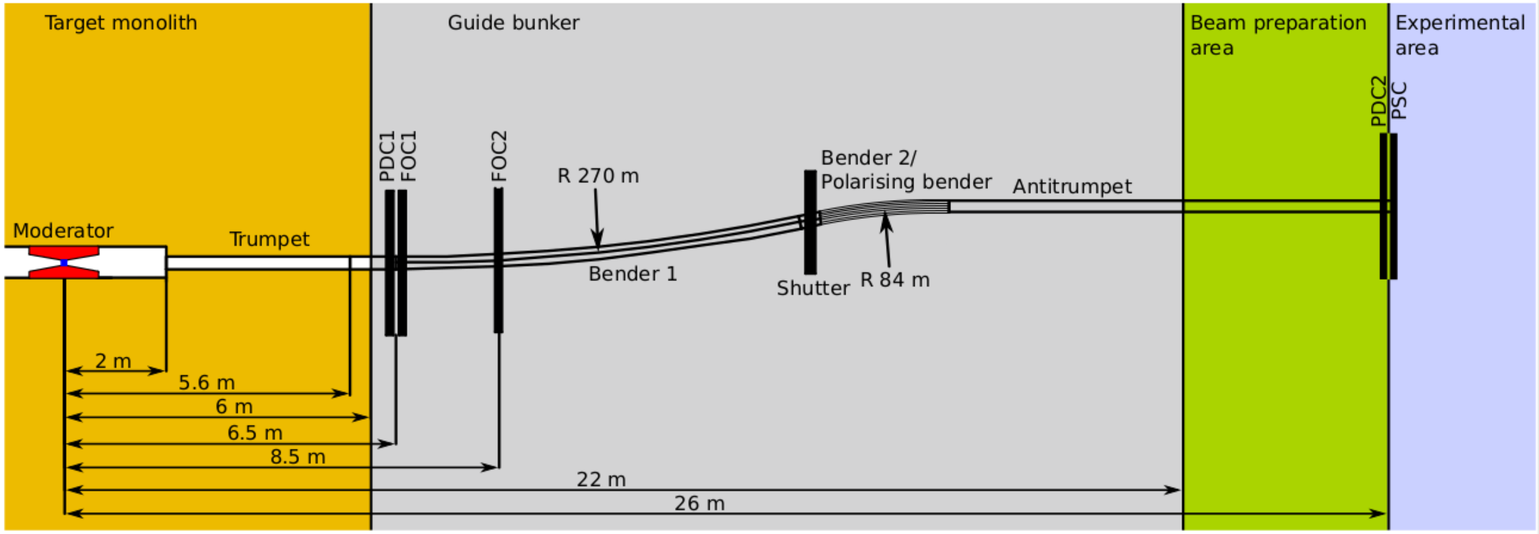
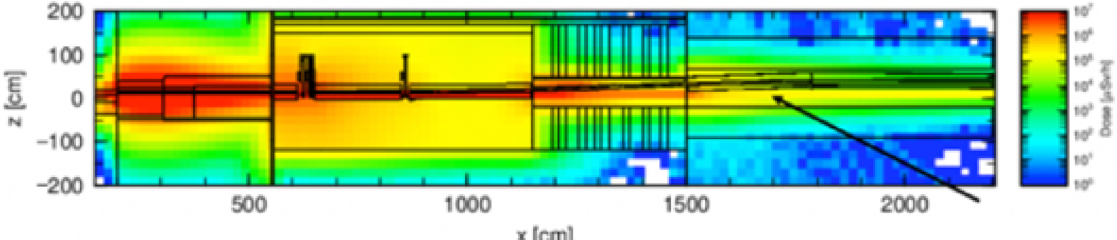


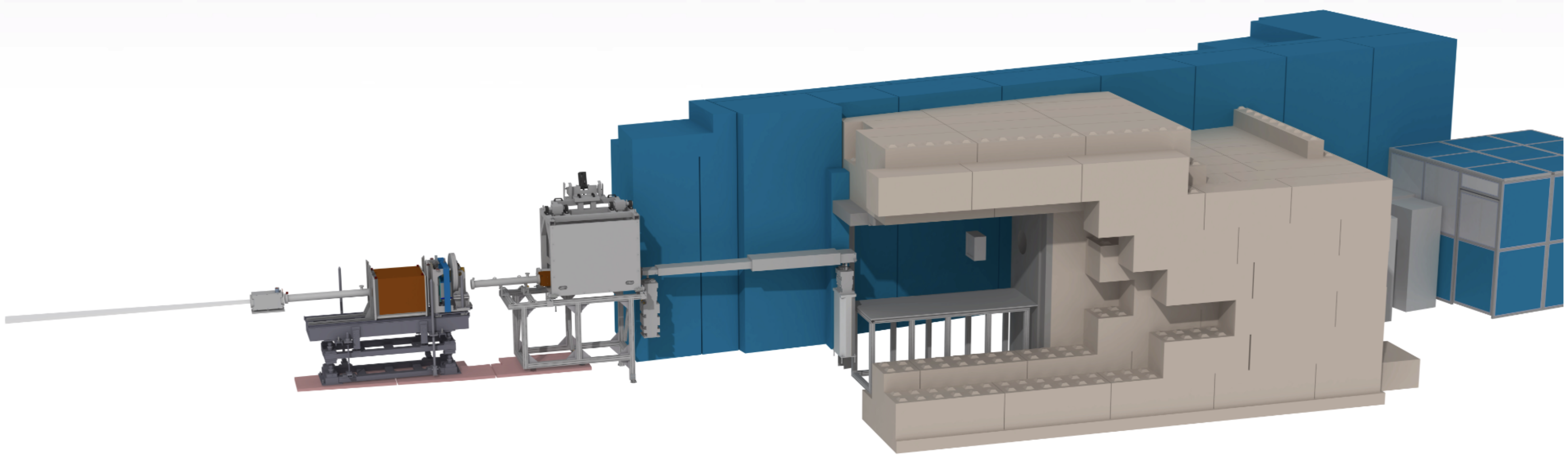


ANNI has a background problem

ANNI will be redesigned

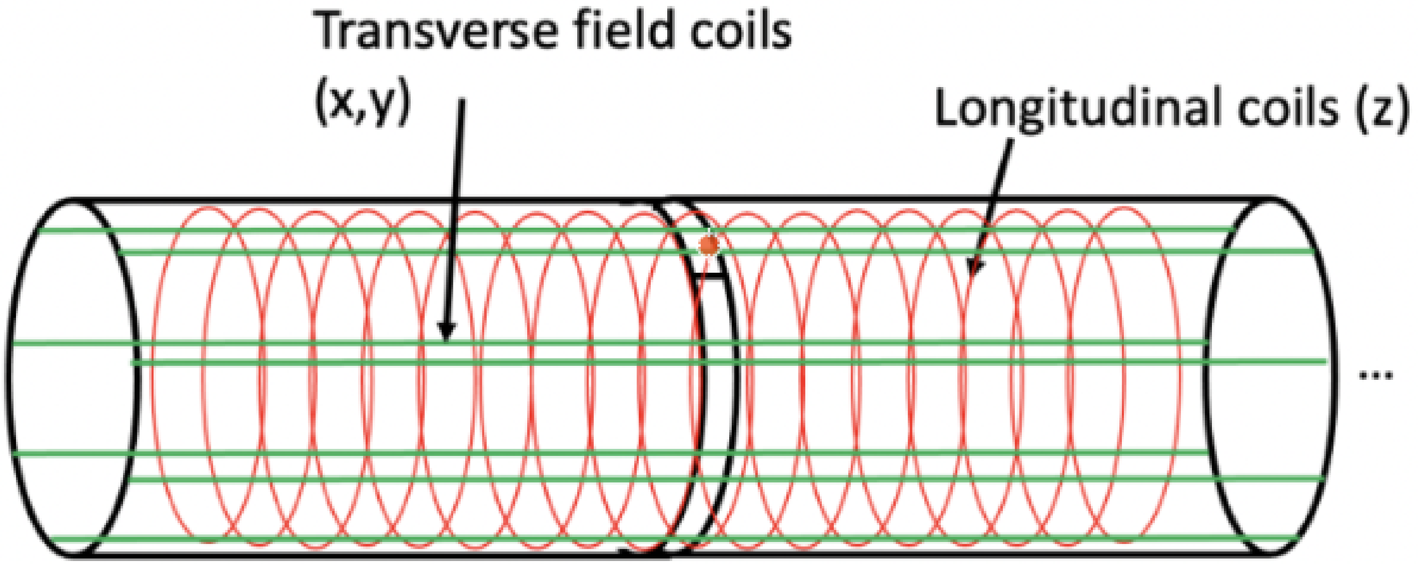
ESS Test Beam Line (TBL)

- Available in the first days of ESS operation (for moderator studies)
- Inexpensive (no neutron guides)
- Flight path of ~15m could be used
- Sensitivity below ANNI, but still beyond currently achieved



Magnetic control beam line

- Full 3D control of the magnetic field will be needed
- Level of ~2 mG.
- Achieved with 3D current coils
- Non-uniformity reduced with mu-metal shielding



WP2: Annihilation Detector

(coordinator: BM)

WP2 Summary

- **Main:** Annihilation detector studies for HIBEAM
- **1. High sensitivity**: large target radius (1m diameter) without full scale calorimeter + TPC + plastic scintillators
- **2. Medium sensitivity** (0.5<diameter<1m): Calorimeter HRD perpendicular layers of scintillating plastic staves + lead-glass EM calorimeter with light guide readout + TPC tracking + silicon strip detectors + plastic scintillators (cosmic veto).
- **3. Lower sensitivity** (diameter <0.5m): WASA calorimeter based on CsI crystals, + TPC tracking + plastic scintillators (cosmic veto).

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Detector options 1 and 2

- Studies based on simulation techniques already developed
- Geometry written in modular way (easy to change it)

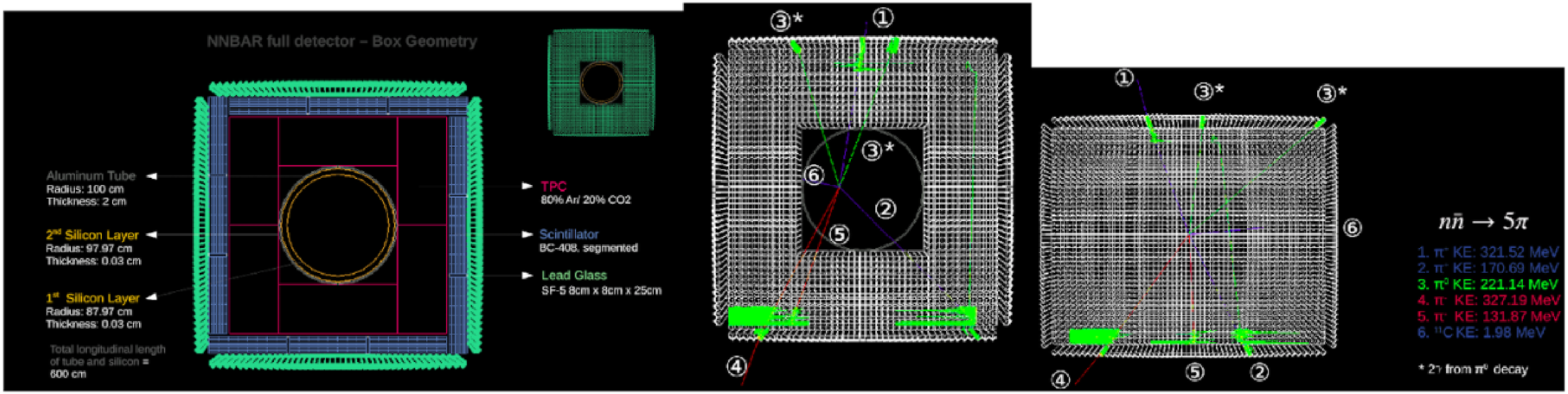
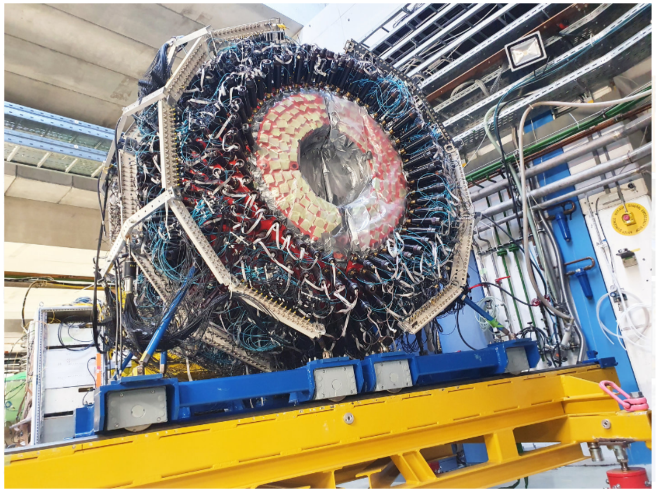


Figure 3: Geant 4 detector display (left), a signal event interfaced with the detector in Geant (right).

Detector option 3: WASA calorimeter and tracking



- Deploy TPC tracking with the WASA calorimeter
- Detector surrounded by a cosmic veto
- UU plays the leading role

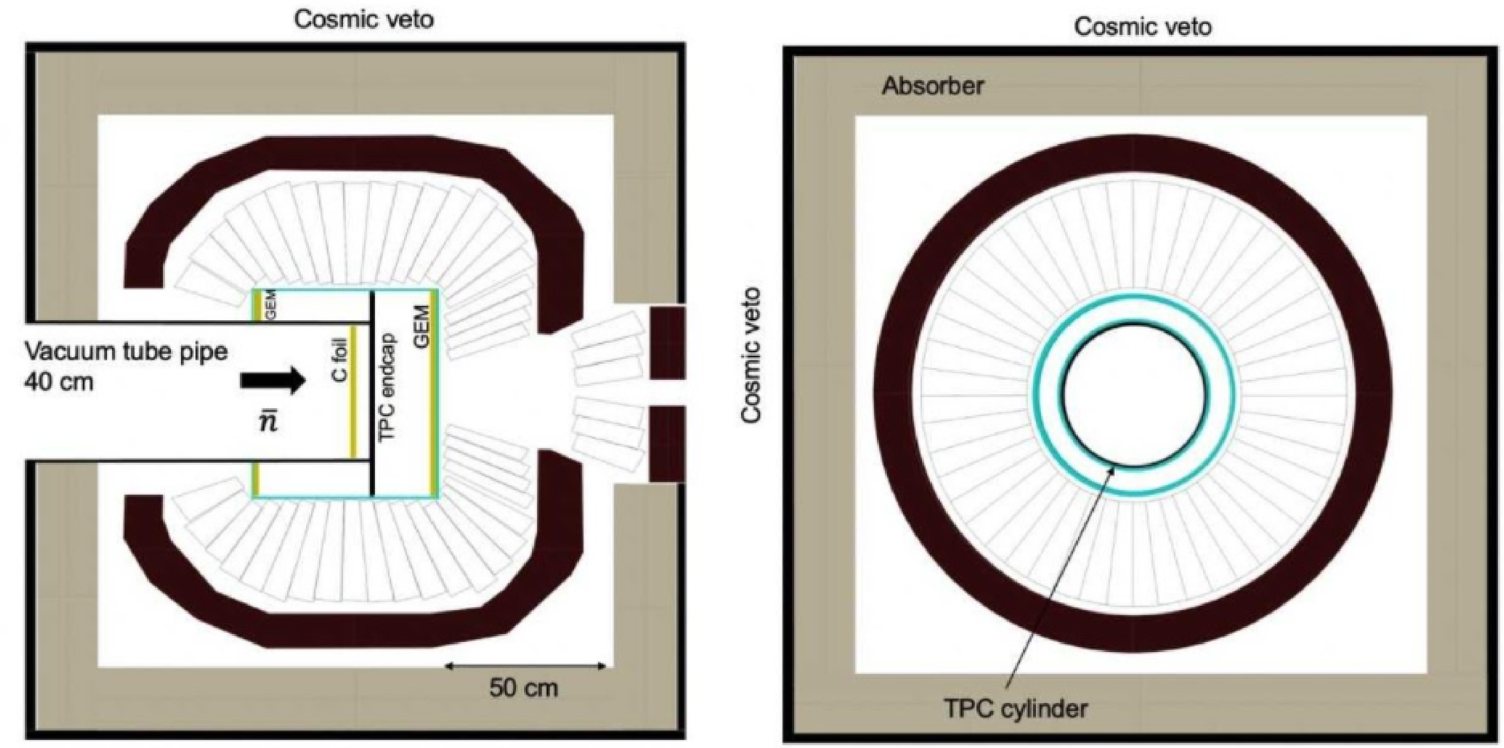
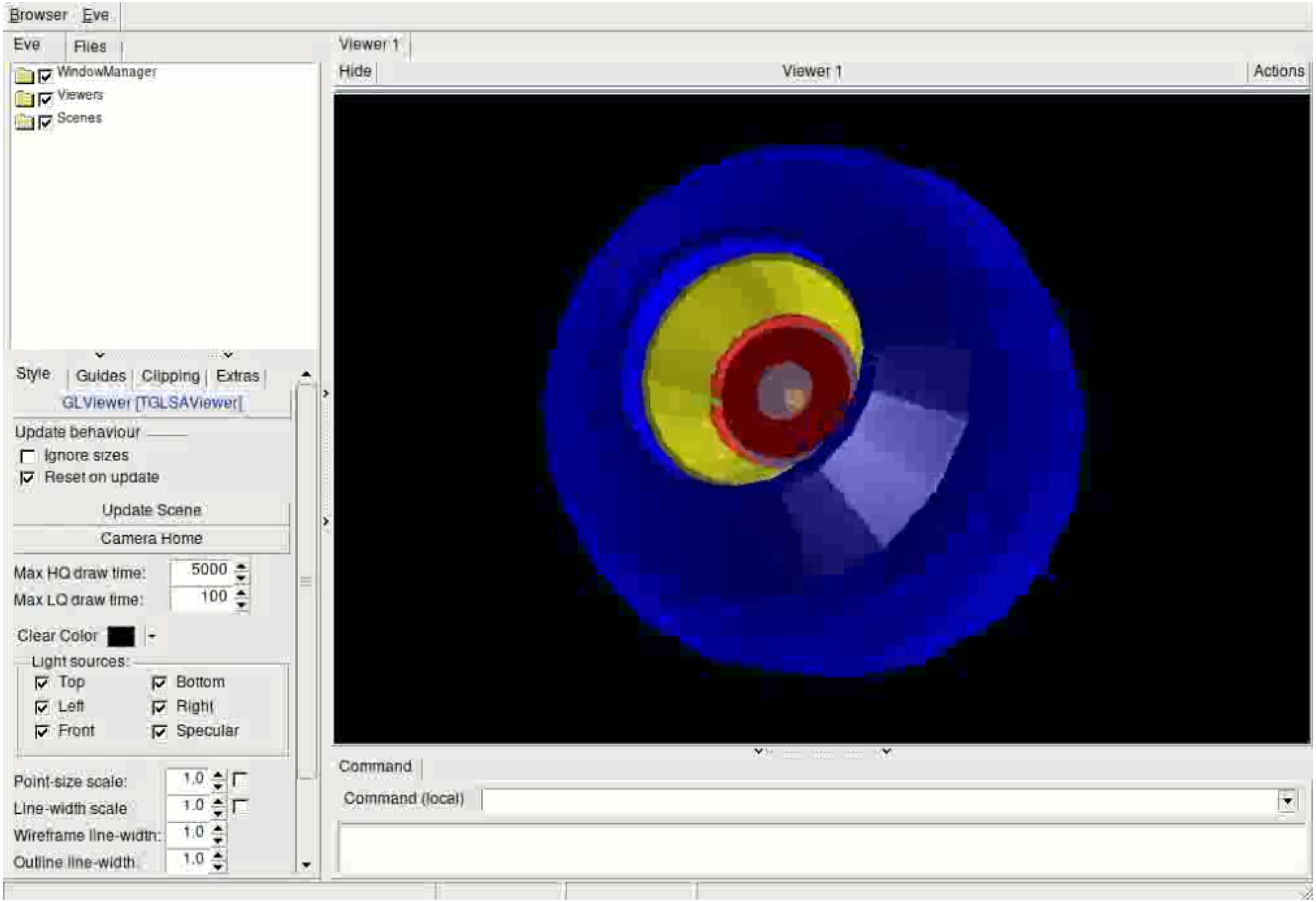


Figure 4: Longitudinal (left) and transverse (right) of the WASA calorimeter with TPC tracking and a cosmic veto.

WASA in Geant4



Implementation of WASA in HIBEAM framework using Super FRS(GSI) code (successfully) ongoing

WP3: Annihilation detector prototype/components R&D and tests

(coordinators: S. Silverstein (SU) and A. Kupsc (UU))

Vetenskapsrådet

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WP3 summary (prototype studies)

- Baseline detector technology:
  - TPC tracker
  - Calorimeter
    - Hadronic range detector (Scintillating staves)
    - EM backing calorimeter (Lead glass)
  - Cosmic veto (scintillator)
  - Fine-resolution tracker layer (Si?)
- Readout/DAQ studies

Focus for WP3 (TPC tracker and calorimeter)

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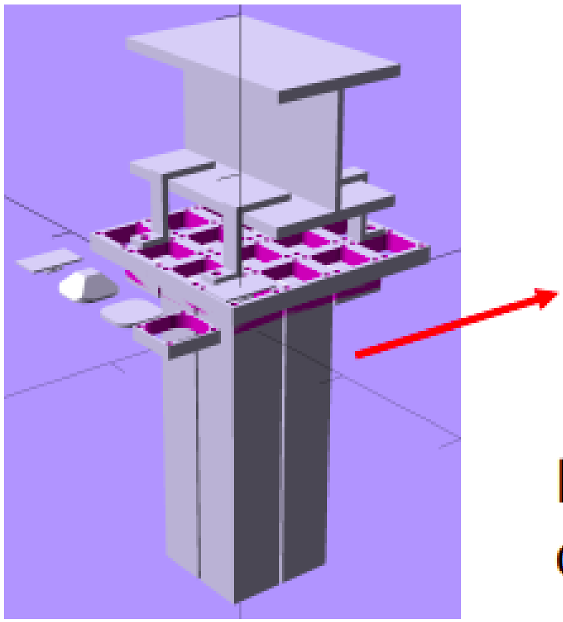
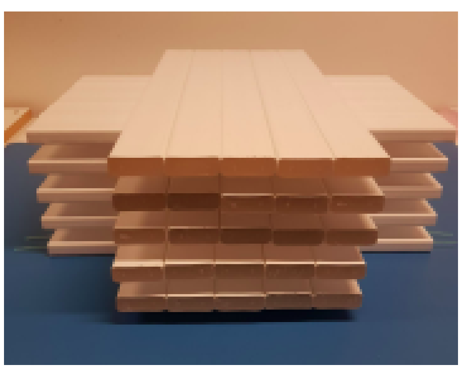
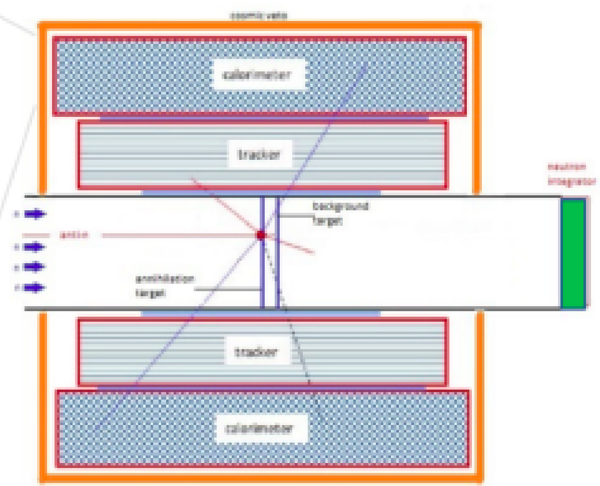
Calorimeter prototype



Lead-glass EM calorimeter



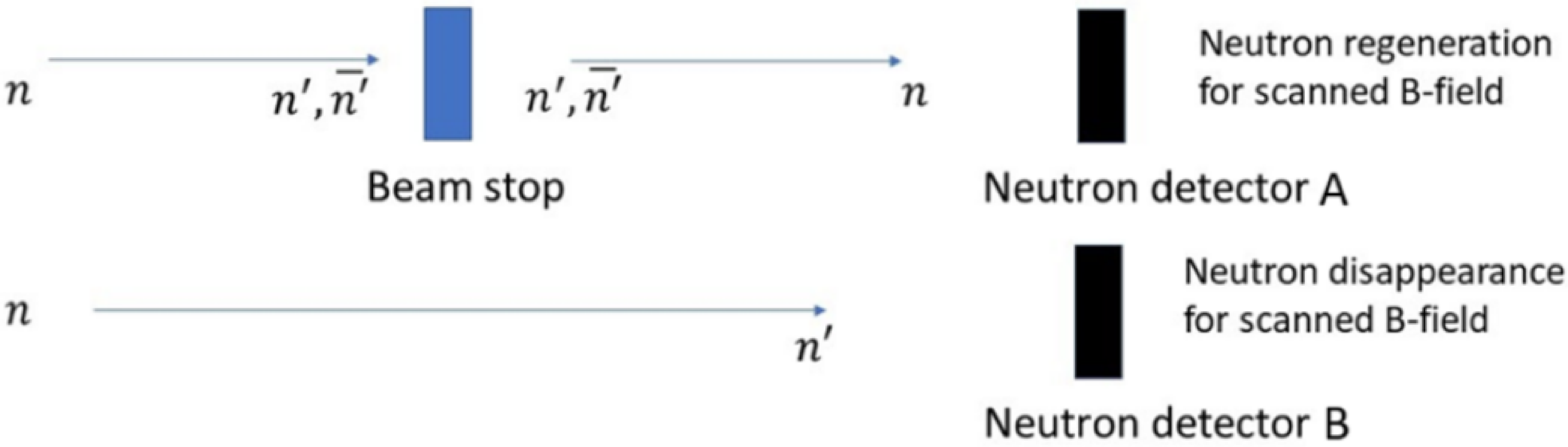
Hadronic range detector (plastic scintillator staves)



WP4: Neutron detectors

(coordinators: H. Perrey and Y. Kashmikov)

Neutron detector design

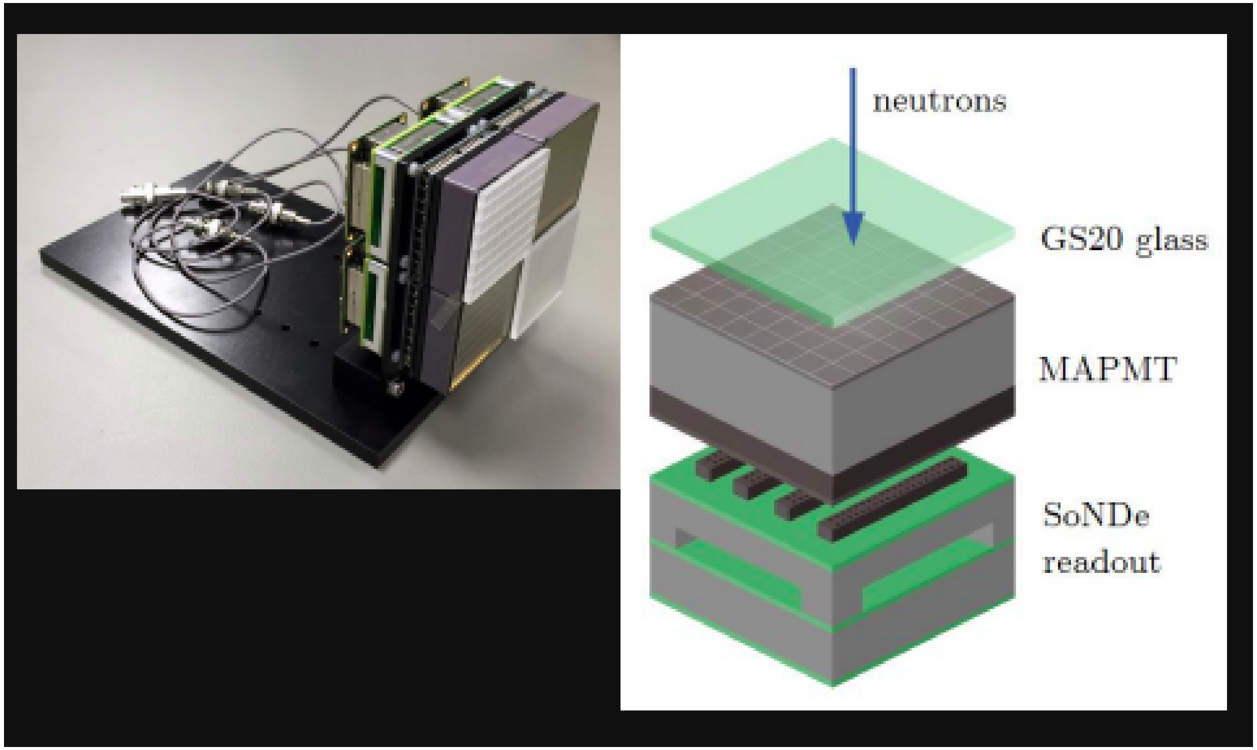


Two very different experiments with very different neutron detector requirements!

- **detector A**: low-flux, large area position-sensitive neutron detector
- **detector B**: high-flux, high-efficiency neutron detector sensitive to intensity variations of 10^{-7}

Goal of WP4: technology review, candidate selection, costing model(s)

Technology choices



- For detector A: Solid State Neutron Detector (SoNDe) or He-3
- Other technologies already exist or are reaching maturity

HIBEAM VR RFI team

- D. Milstead (project coordinator)
- WP1: V. Santoro, P. Fierlinger, M. Holl
- WP2: B.M., B. Yiu, M. Wolke, L. Eklund, T. Nilsson, H. Johansson
- WP3: S. Silverstein A. Kupsc, K. Dunne, A. Oskarsson
- WP4: H. Perrey, Y. Kashmikov

MAJOR REPORT • OPEN ACCESS

New high-sensitivity searches for neutrons converting into antineutrons and/or sterile neutrons at the HIBEAM/NNBAR experiment at the European Spallation Source

A Addazi[1,2], K Anderson[7], S Ansell[8], K S Babu[9], J L Barrow[10], D V Baxter[11,12,13], P M Bentley[14], Z Berezhiani[15,16], R Bevilacqua[14], R Biondi[15], C Bohm[17], G Brooijmans[17], L J Broussard[7], J Cederkäll[18], C Crawford[19], P S B Dev[20], D D DiJulio[14], A D Dolgov[21,22], K Dunne[17], P Fierlinger[3], M R Fitzsimmons[10], A Fomin[23], M J Frost[7], S Gardiner[7], S Gardner[19], A Galindo-Uribarri[7], P Geltenbort[24], S Girmohanta[4], P Golubev[18], E Golubeva[25], G L Greene[10], T Greenshaw[26], V Gudkov[27], R Hall-Wilton[14], L Heilbronn[10], J Herrero-Garcia[28], A Holley[29], G Ichikawa[30], T M Ito[31], E Iverson[7], T Johansson[32], L Jönsson[32], Y-J Jwa[17], Y Kamyshkov[10], K Kanaki[14], E Kearns[33], Z Kokai[14], B Kerbikov[34,35,36], M Kitaguchi[37], T Kittelmann[14], E Klinkby[38], A Kobakhidze[39], L W Koerner[40], B Kopeliovich[22], A Kozela[41], V Kudryavtsev[42], A Kupsc[31], Y T Lee[14], M Lindroos[14], J Makkinje[43], J I Marquez[14], B Meirose[17,18], T M Miller[14], D Milstead[68,17], R N Mohapatra[44], T Morishima[36], G Muhrer[14], H P Mumm[45], K Nagamoto[36], A Nepomuceno[46], F Nesti[16], V V Nesvizhevsky[24], T Nilsson[47], A Oskarsson[18], E Paryev[25], R W Pattie Jr[48], S Penttil[7], H Perrey[18], Y N Pokotilovski[18], I Potashnikovav[40], K Ramic[14], C Redding[49], J-M Richard[50], D Ries[51], E Rinaldi[52,53], N Rizzi[37], N Rossi[15], A Ruggles[49], B Rybolt[54], V Santoro[14], U Sarkar[55], A Saunders[14], G Senjanovic[56,57], A P Serebrov[23], H M Shimizu[36], R Shrock[4], S Silverstein[17], D Silvermyr[18], W M Snow[11,12,13], A Takibayev[14], I Tkachev[25], L Townsend[58], A Tureanu[59], L Varriano[60], A Vainshtein[61,62], J de Vries[63,64], R Wagner[24], R Woracek[14], Y Yamagata[65], S Yiu[17], A R Young[66], L Zanini[14], Z Zhang[67] and O Zimmer[24] – Hide full author list

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Summary and outlook

- HIBEAM-NNBAR two stage program at ESS
- HIBEAM – world leading sterile neutron searches + pilot free $n \rightarrow \bar{n}$ search
- VR RFI grant for HIBEAM pre-studies (research needed ahead of a formal beamline proposal)
- Work packages address all major areas, and involve several Swedish institutes:

(1) Beamline design (ESS)
(2) Detector design (SU,LU,CTU,UU)
(3) Prototype tests (SU,LU,UU)
(4) Neutron detectors (LU, ESS)