TUCAN EDM

TRIUMF Ultra-Cold Advanced Neutron project

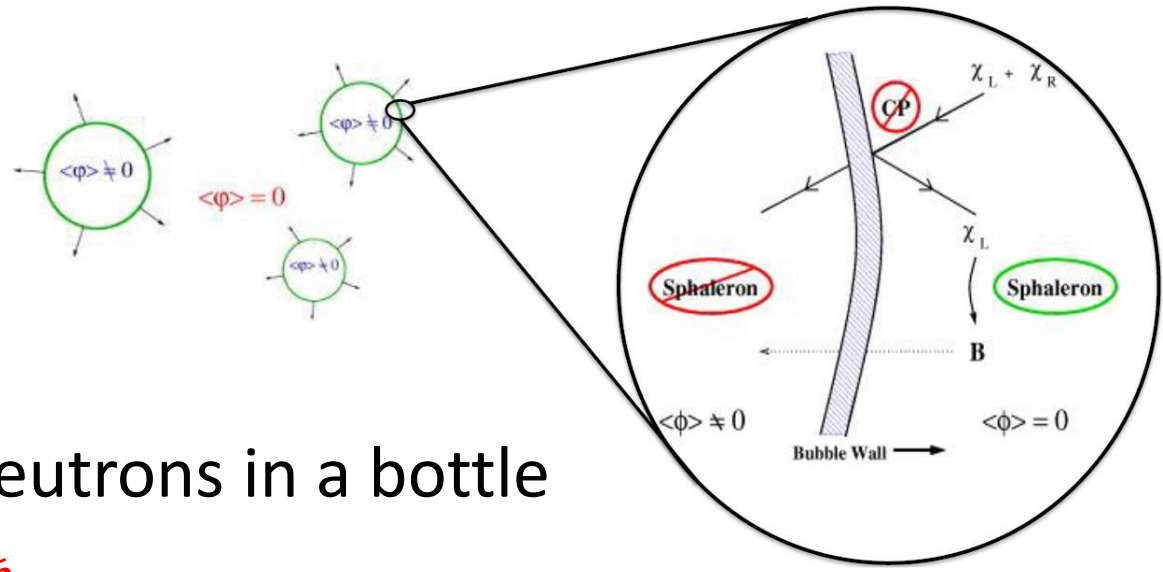
Jeff Martin, The University of Winnipeg

TUCAN
Collaboration

TRIUMF PP-EEC, March 24, 2022

Physics of Neutron Electric Dipole Moment

- Search for new sources of CP violation beyond the standard model.
- Motivated by:
  - New physics for electroweak baryogenesis
  - SUSY CP problem / new TeV-scale physics
  - Strong CP problem / Peccei-Quinn, axions
  - Other new physics scenarios
- Spin precession frequency of ultracold neutrons in a bottle

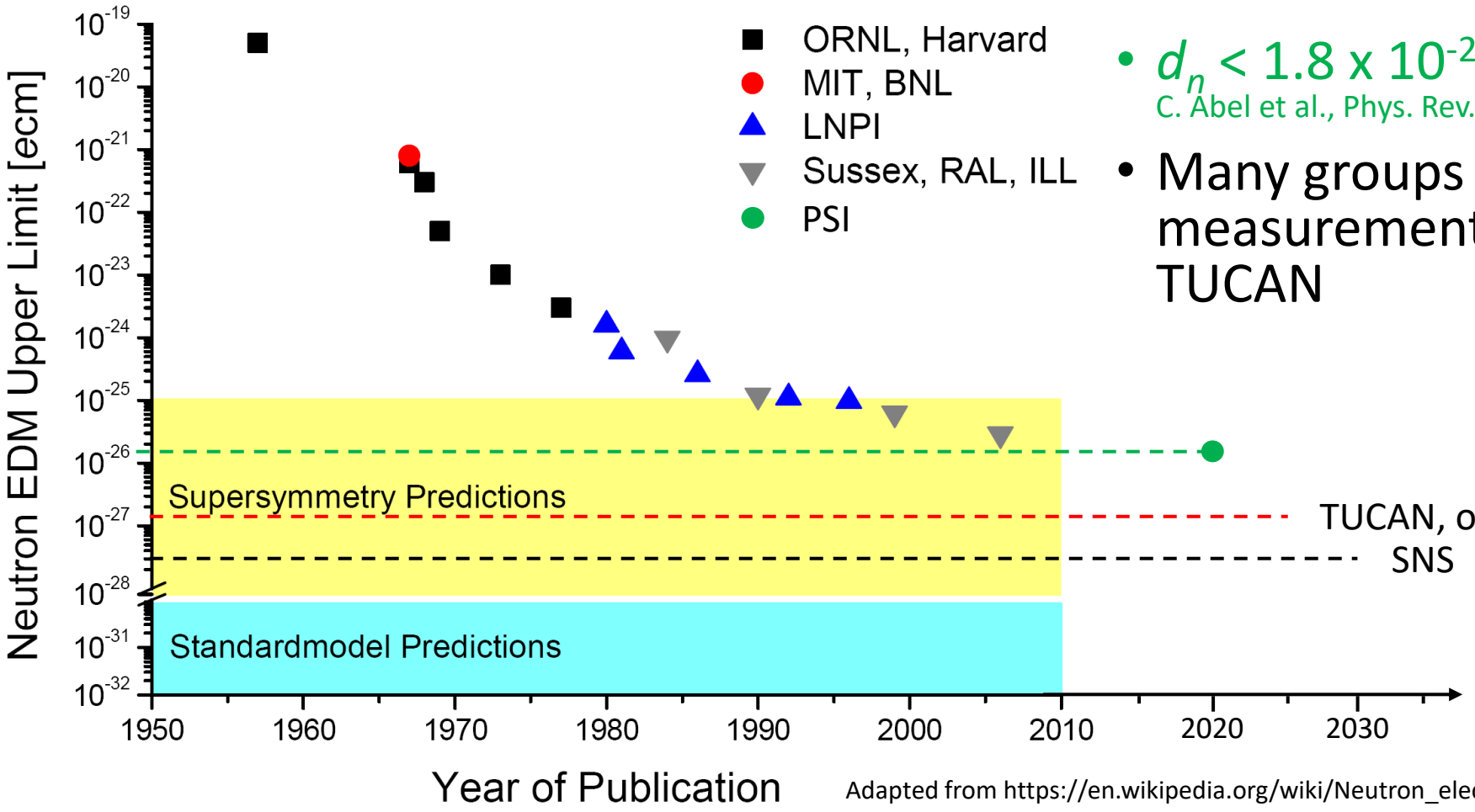


Adapted from Morrissey & Ramsey-Musolf New J. Phys. 2012

$$h\nu = 2\mu B \pm 2dE \qquad \sigma_d = \frac{\hbar}{2\alpha E T\sqrt{N}}$$

TUCAN goal: $\sigma_d = 1 \times 10^{-27}$ $e$cm in 400 days of running.

Neutron EDM – experimental status



- $d_n < 1.8 \times 10^{-26}$ *e*cm (90% C.L.)
  C. Abel et al., Phys. Rev. Lett. 124, 081803 (2020)
- Many groups pursuing ~ 10^{-27} *e*cm measurement as next step, including TUCAN

New UCN source technology

Adapted from https://en.wikipedia.org/wiki/Neutron_electric_dipole_moment

TUCAN: Uniqueness and competitive edge

- Spallation-driven He-II UCN source can surpass competing so-D_2 UCN sources (longer UCN storage times) and reactor-driven He-II sources (lower heating per unit neutron flux).
- Proven technology of room-temperature neutron EDM experiment. Low risk with window of opportunity to surpass fully cryogenic experiments.
- Unique features of our neutron EDM experiment:
  - Self-shielded B_0 coil.
  - NMOR-based magnetometers.
  - R&D on possible Xe comagnetometer (farther future).
- And are building on the R&D of other groups:
  - Magnetically shielded room (MSR).
  - Dual measurement cells.

TUCAN Collaboration

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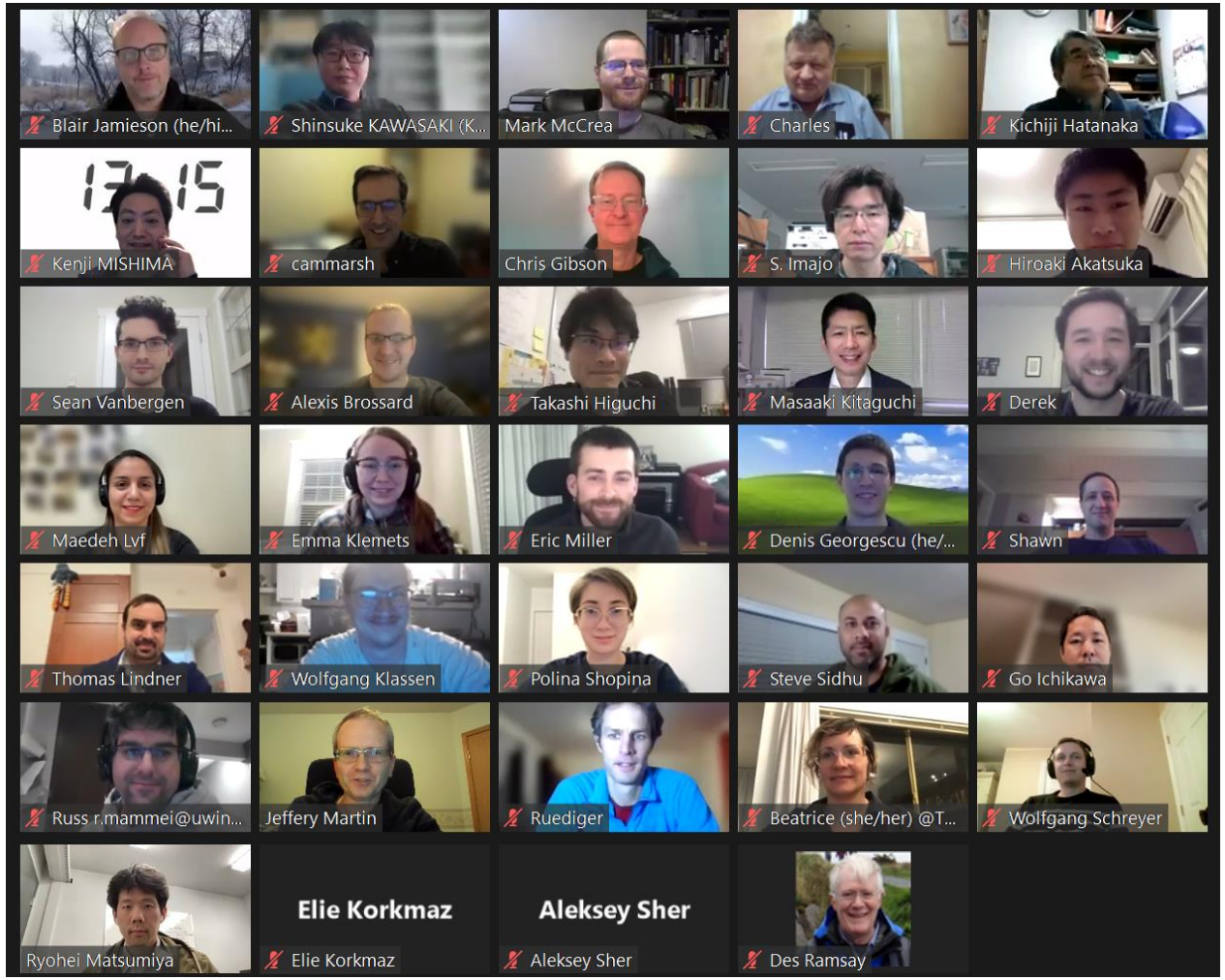
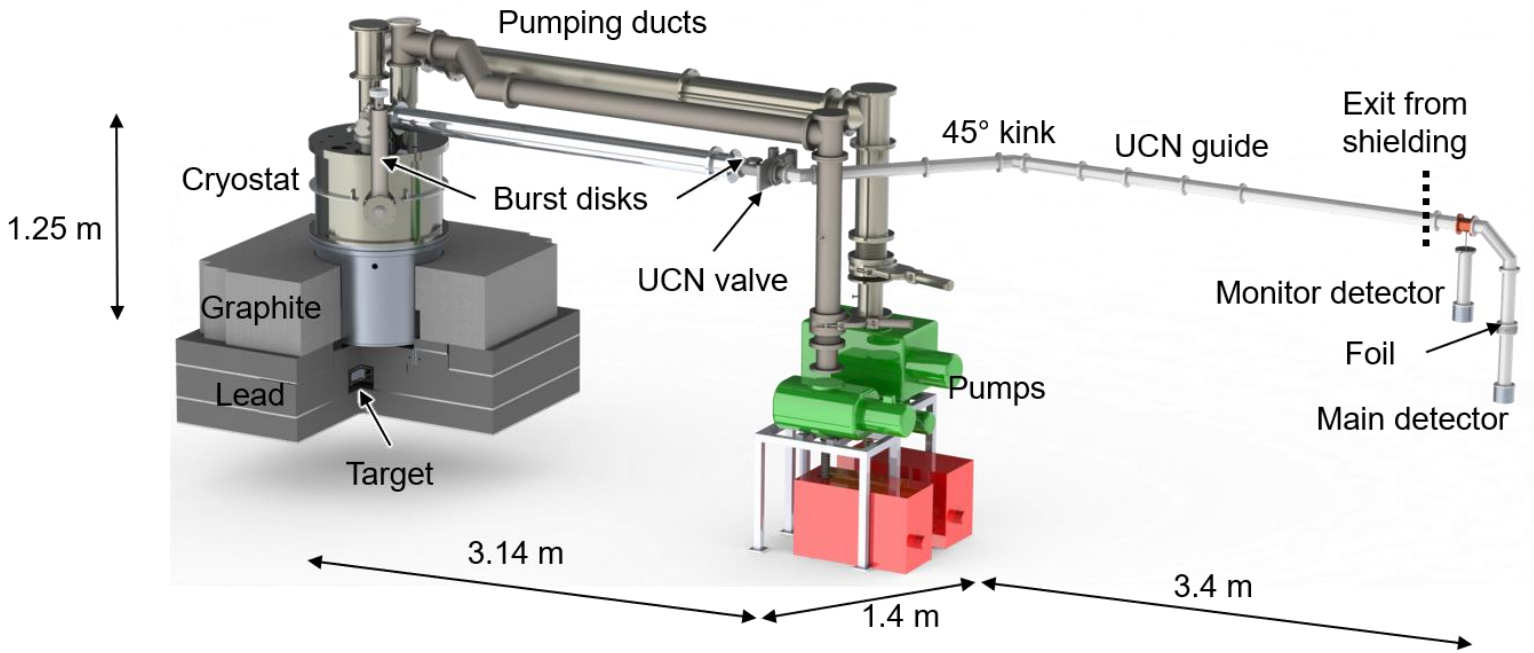
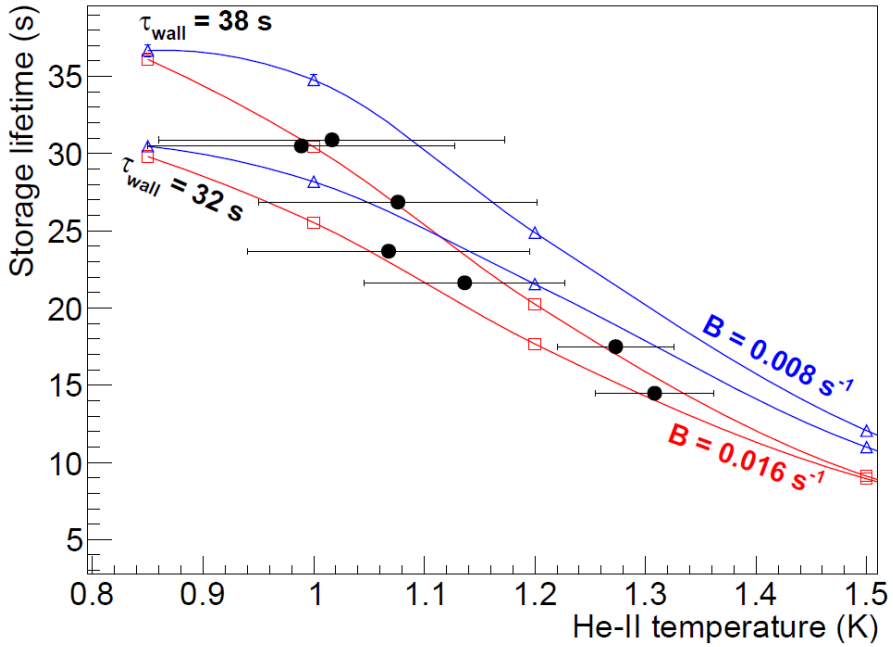


Jan. 2022 virtual collaboration meeting

Previous “Vertical” UCN Source at TRIUMF

S. Ahmed *et al.* (TUCAN Collaboration)
Phys. Rev. C **99**, 025503 (2019)



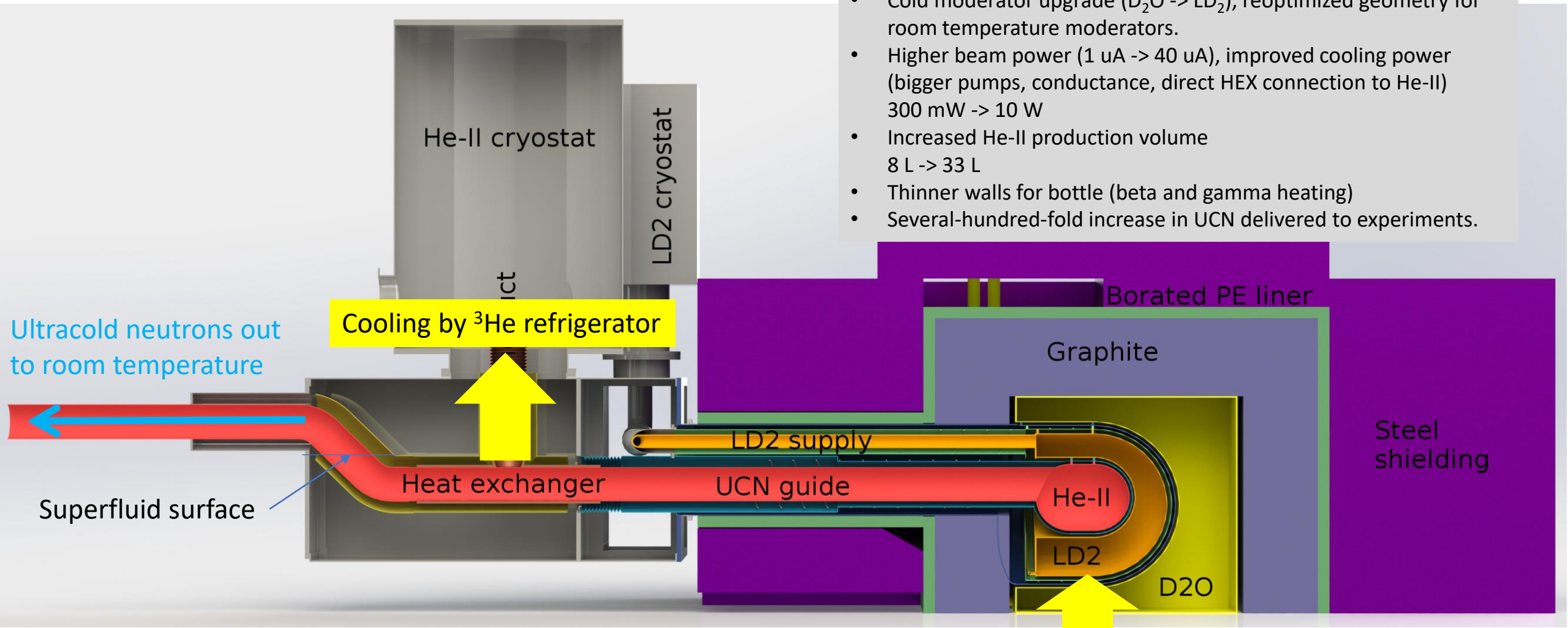


- In preparation (Phys. Rev. C): new data that collapses the horizontal error bars on this plot (<~ 0.01 K).
- Allows extraction of the parameters describing the interaction of UCN with phonons in the He-II.

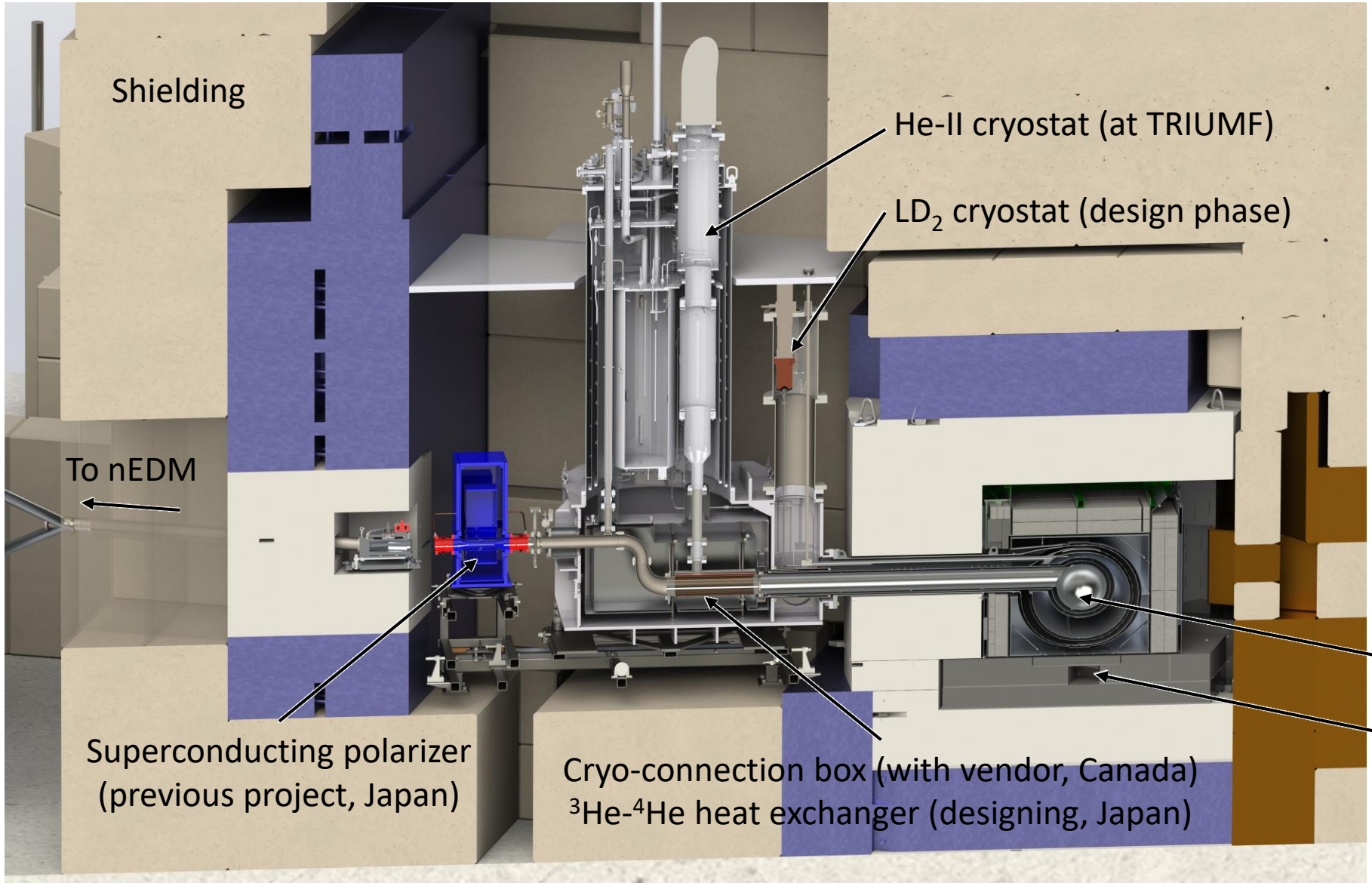
Ongoing upgrade: Next generation He-II cryostat (the "horizontal source")

Improvements compared to "vertical" source

- Material potential He-II is 18 neV, use near-horizontal extraction
- Cold moderator upgrade (D_2O -> LD_2), reoptimized geometry for room temperature moderators.
- Higher beam power (1 uA -> 40 uA), improved cooling power (bigger pumps, conductance, direct HEX connection to He-II) 300 mW -> 10 W
- Increased He-II production volume 8 L -> 33 L
- Thinner walls for bottle (beta and gamma heating)
- Several-hundred-fold increase in UCN delivered to experiments.



Horizontal source status



Tail section (testing/fab)

Target (previous project)

Top view

(Pumps in place, preparing for testing)

^{3}He pumps

^{nat}He pumps

Cryostat pit

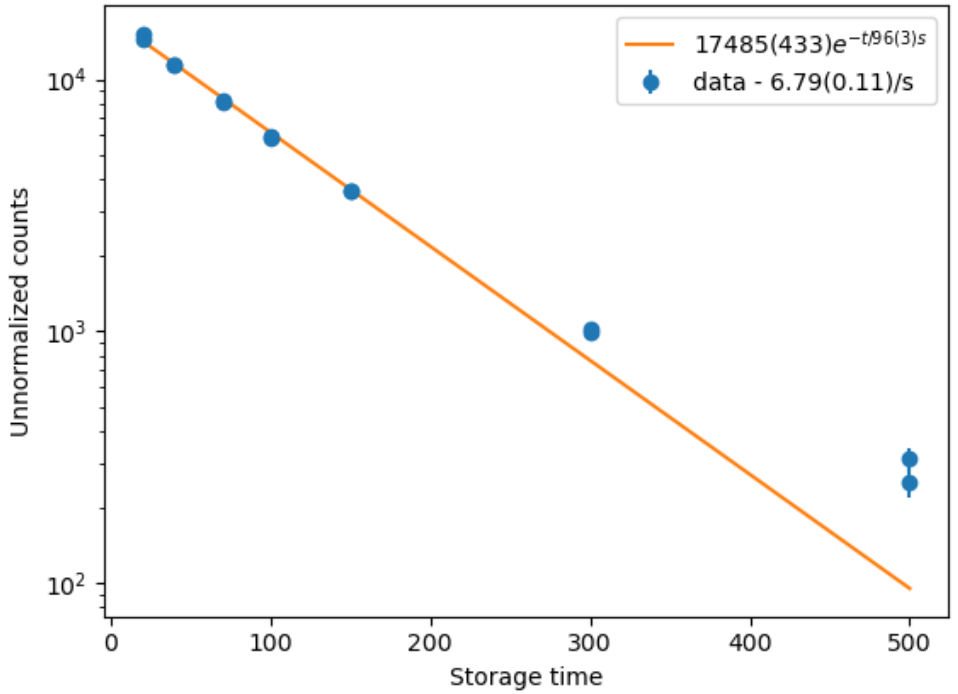
Access door

To nEDM

New “horizontal” source progress

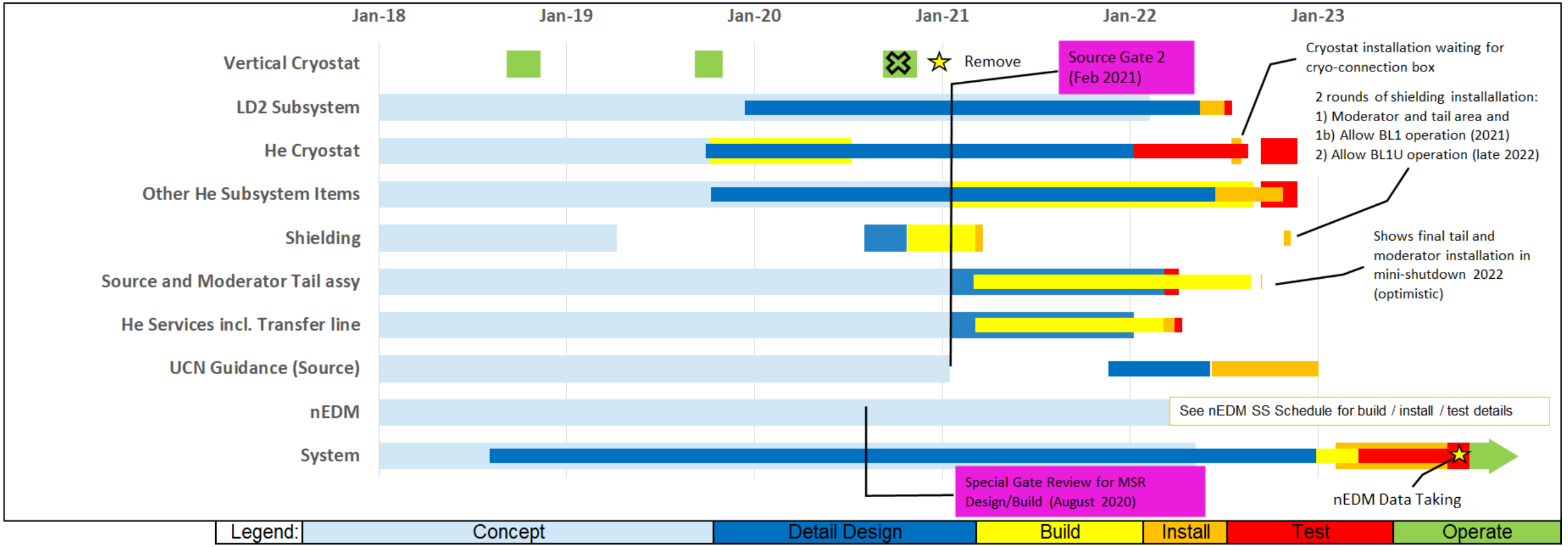
- He-II cryostat
  - arrived at TRIUMF (July 2021). Reassembly completed. Room-temperature leak-checking nearly complete.
- Tail section and cryo-connection box
  - Engineering design completed.
  - Cryo-connection box contract signed.
  - Test of tail section “wall 1” with ultracold neutrons at LANL (required by TUCAN EAC review committee, 2020) (Nov. 2021).
  - All other components of tail section being manufactured. Preparing for welding at TRIUMF.
- Pumps that provide cooling to source arrived at TRIUMF (Oct. 2021).
- Transfer line from liquefier to source arriving soon (Apr. 2022).

Tail section wall 1 (He-II vessel)



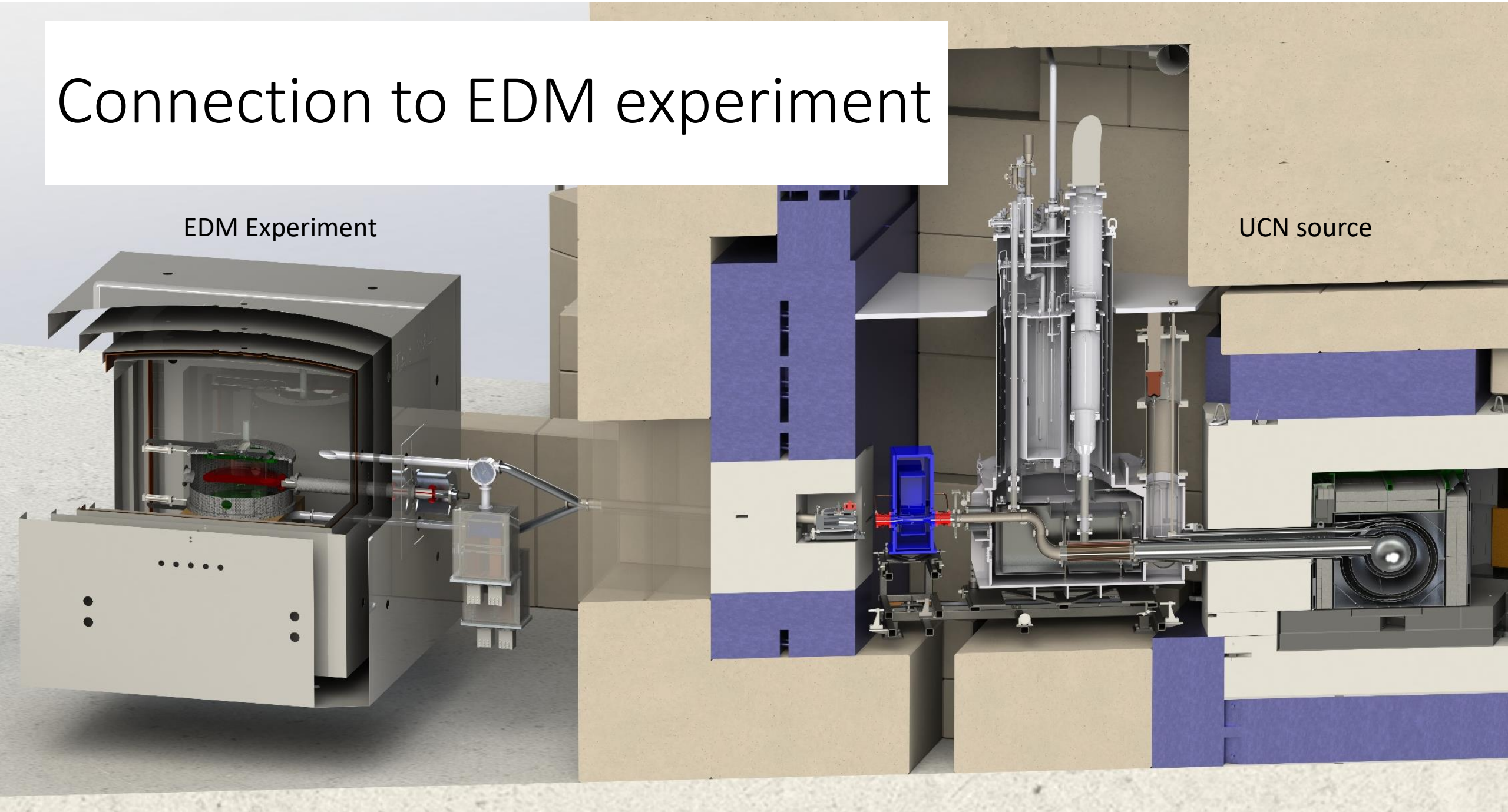
- Storage time 96 s in upper, 40 s in lower position.
- Loss per bounce ~ (4-8) x 10^{-4}
- Higher loss/bounce, but acceptable
- Clean carefully, implement in tail section.

UCN Source Schedule

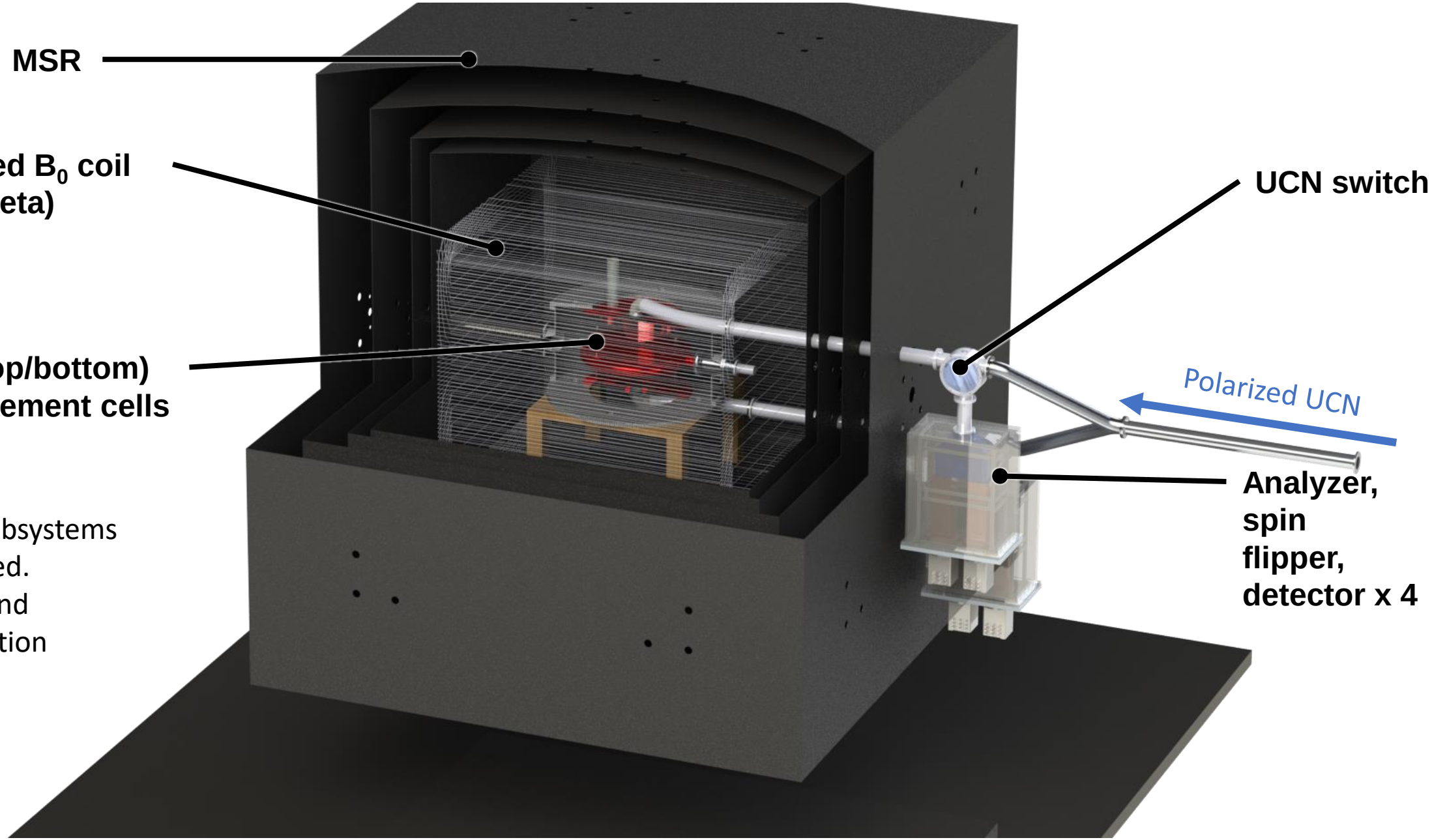


- All schedules assumed work in cryostat pit can continue during 1A running.
- Might not be possible, work with rad. protect. group to find solution.

Connection to EDM experiment



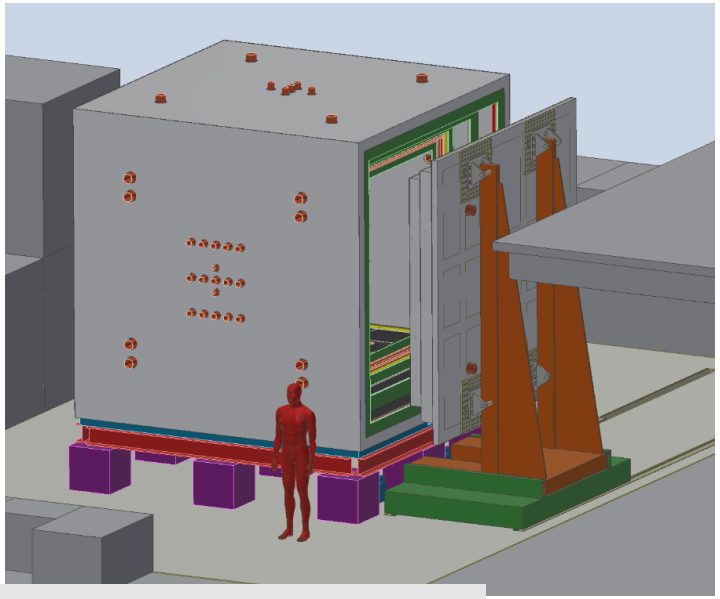
TUCAN EDM experiment layout



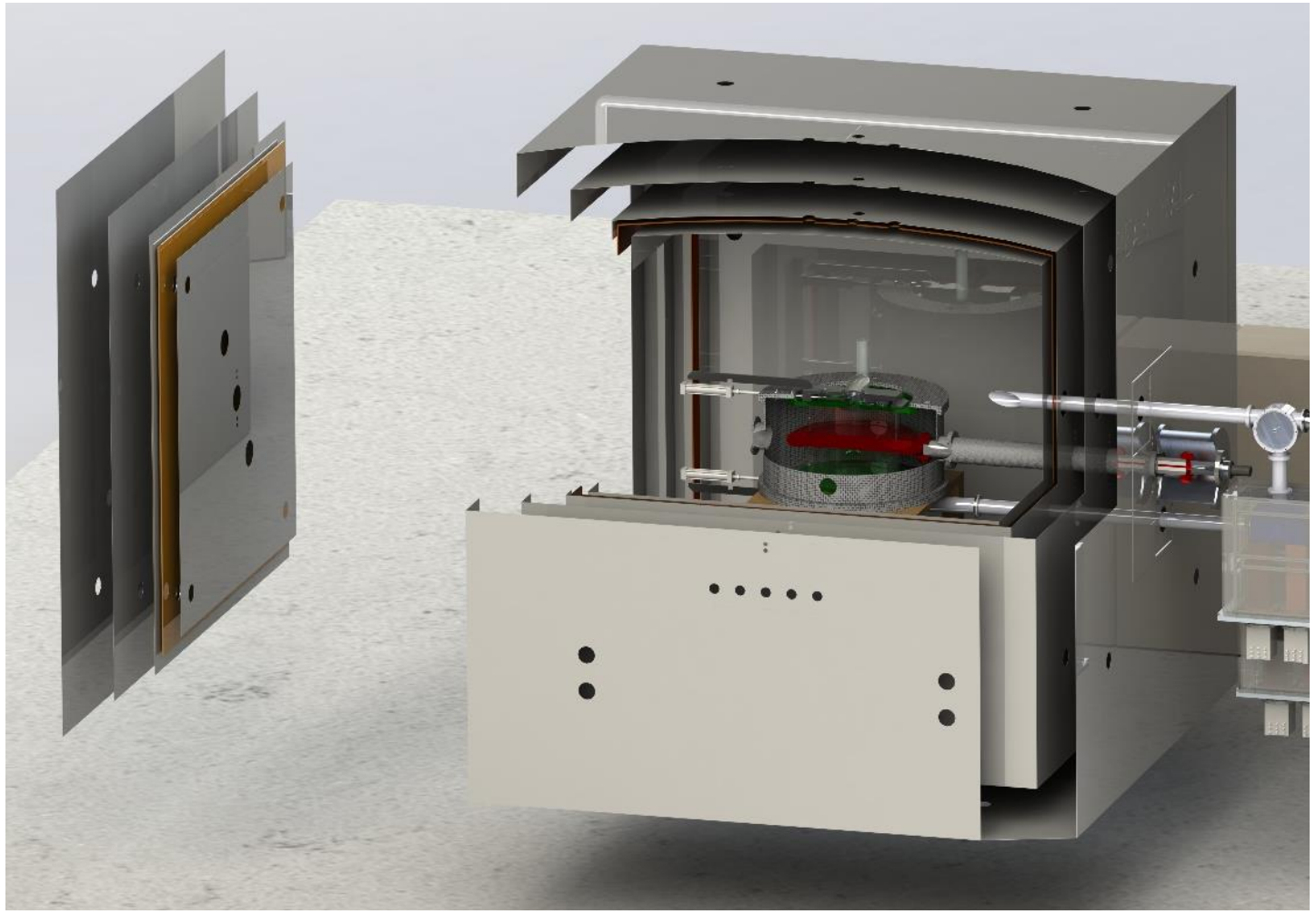
- Major subsystems developed.
- Design and construction phase.

Magnetically shielded room (MSR)

- Final design/fab in progress (inner floor and Cu layer are all that remains for design work).
- Installation begins July 2022, completed 2023.



Door motion mechanism

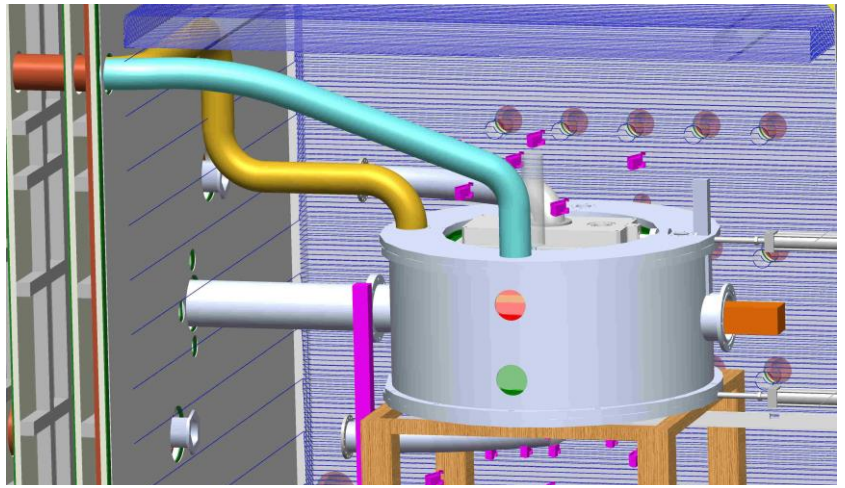


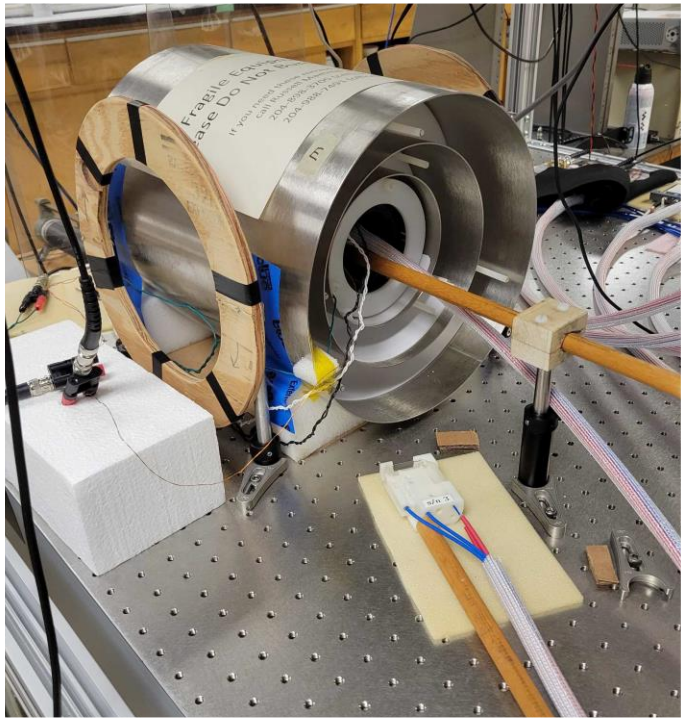
More progress (EDM subsystems)

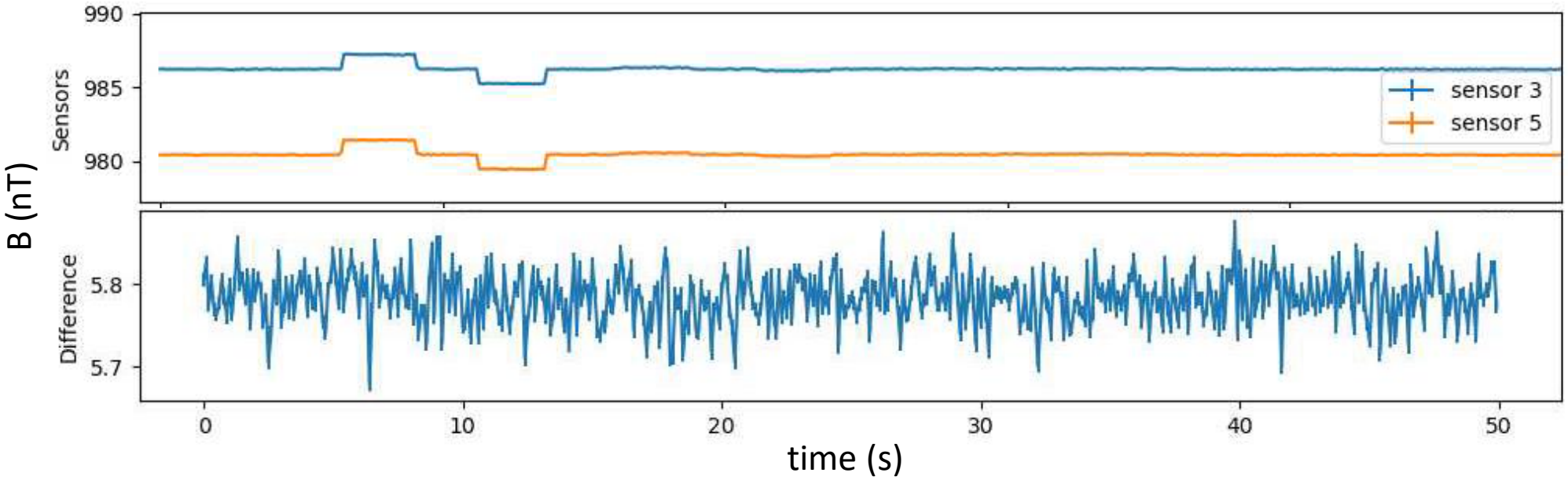
- Equipment in the mechanical design/construction phase:
  - External field compensation (RCNP Osaka, TRIUMF) (design phase)
  - Internal coils (Winnipeg, TRIUMF) (proto., nearing construction)
  - UCN detector (Winnipeg) (proto., test at J-PARC 2022)
  - UCN spin analysis (Winnipeg, RCNP Osaka, TRIUMF) (design, test at J-PARC 2022)
  - HV/cell/valves/central region (TRIUMF) (proto., test at J-PARC 2022)
  - Hg comagnetometer and Xe development lab (UBC) (proto., prep. design)
  - NMOR-based Cs magnetometers (Winnipeg) (5 completed, 5 on order)
- Challenge: budget.
  - Cost overruns in UCN source (driven by pandemic cost increases) have forced us to re-evaluate our budget. This may lead to descoping/rescoping the EDM experiment. This will be a major element of our upcoming EAC review.

Example: Cs NMOR sensors

- Fully non-magnetic Cs sensors with no electric parts.
- Precise to ~ pT/rtHz
- Key requirement of < pT frequency shifts difficult to measure (need MSR)



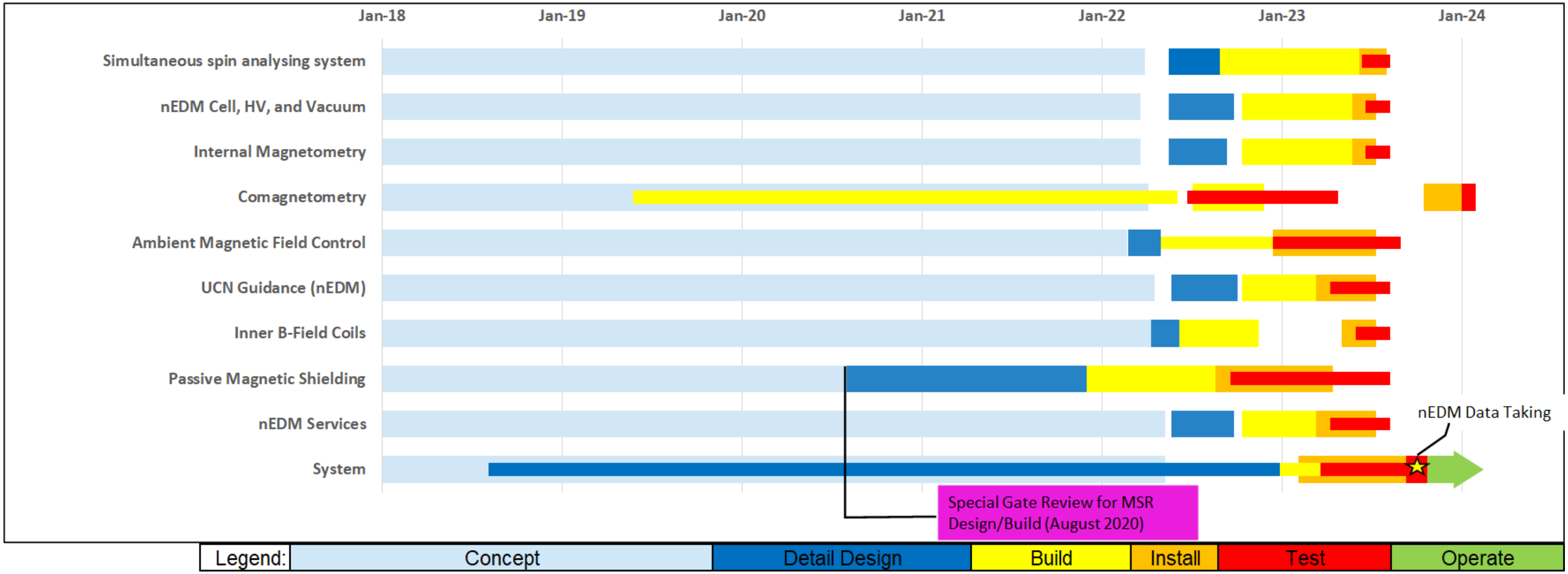




Can now operate five sensors at once. Five more on order.

(But can only fit two in our small magnetic shield – looking forward to MSR!!!)

EDM Schedule



- MSR schedule is most up to date and realistic.
- Recent large push to get other subsystems incorporated more fully.

TUCAN Plans

- 2021-2023:
  - Complete the upgrade of the UCN source
  - Design and build the nEDM experiment
  - Commission UCN source with beam (2023)
- 2023:
  - Commission MSR (magnetic testing)
  - First beam to nEDM experiment (likely 2024)
- Beyond (2024-):
  - Run the nEDM experiment for statistics, and systematics studies
  - Develop user facility and other experiments
- Transition from C. Marshall to J. Chak as project engineer. C. Marshall will focus on LD_2 cryostat completion.
- Funding Board (FB) and Expert Advisory Committee (EAC) will review our progress in May 2022.

EAC Review – elements of draft charge

1. Review the cost, schedule, and personnel plan for the project. Review the competitiveness of the project considering the descoping/rescoping needs.
2. Review the status, progress and plans for the UCN source.
3. Evaluate the plan and feasibility for the LD2 cold moderator system.
4. Review progress on the nEDM experiment.
5. Evaluate the proposed scope reduction and rebaselining plan for the nEDM experiment.
6. Review the future upgrade plan, in light of the descoping.

Conclusions

- Strong physics interest with tight constraint placed on CP violation.
- Highly competitive field with many new ideas, technologies.
- TUCAN EDM experiment aims at 10^{-27} *e*cm uncertainty, order of magnitude improvement on previous best experiment.
- TUCAN source upgrade complete by 2023. Neutron EDM experiment installation on track with MSR being installed in 2022-23.
- Preparing for upcoming EAC review (May 2022).

Thank you!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