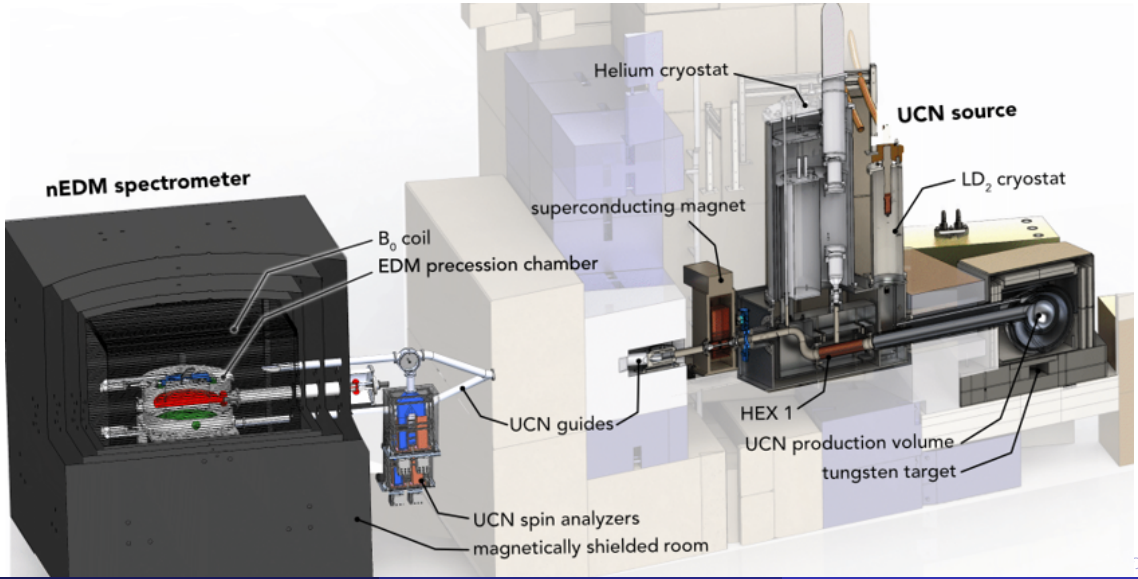
Current Status of the TUCAN EDM Experiment

M. McCrea

University of Winnipeg
TRIUMF Ultra-Cold Advanced Neutron Collaboration

CAP 2023 Fredericton
2023/06/20

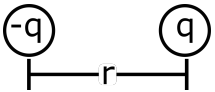
TRIUMF Ultra-Cold Advanced Neutron Source and EDM experiment



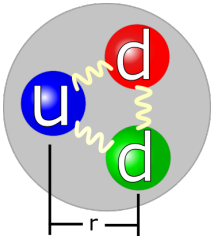
What is an nEDM?

The electric dipole moment, d for two charges of opposite sign and equal magnitude q separated by distance r is classically defined as

$$d = qr.$$



The neutron will have an EDM is there is an average separation of the oppositely charged quarks.



Why Measure a Neutron EDM?

- Neutron EDM searches are part of a searches for new sources of CP violation in the Standard Model.
- The Hamiltonian for a neutron in an electric and magnetic field can be written as:

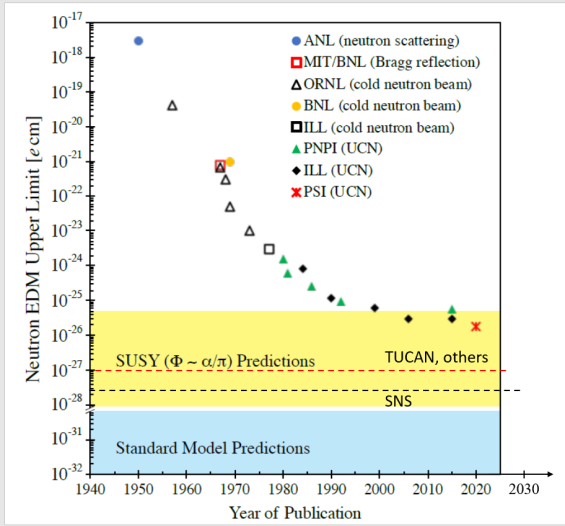
$$\mathbf{H} = -\mu \mathbf{B} \frac{\mathbf{s}}{s} - d\mathbf{E}\frac{\mathbf{s}}{s}$$

and under a time inversion transformation

$$T\mathbf{H} = -\mu \mathbf{B} \frac{\mathbf{s}}{s} + d\mathbf{E}\frac{\mathbf{s}}{s}$$

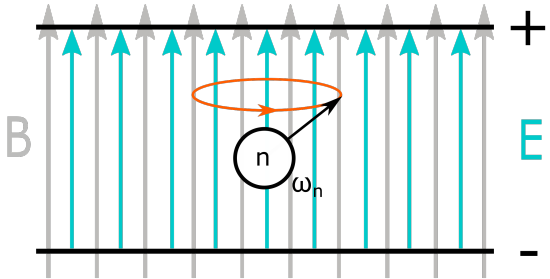
- the EDM term violates time reversal symmetry T, and from the CPT theorem, also violates CP symmetry.

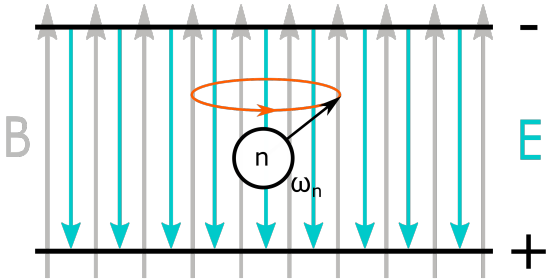
History of nEDM Measurements



- Current Best Limit: $d_n < 1.8 \times 10^{-26} e{\cdot}\text{cm}$ (90% C.L.) from PSI experiment, C. Abel et al., PRL 124, 081803 (2020)
- The TUCAN collaboration aims to make a measurement sensitive to $1 \times 10^{-27} e{\cdot}\text{cm}$.
- Red point is the first experiment ever to use a "superthermal" UCN source.
- We plan to make the curve take a sharp downward turn, using new UCN source technology.

nEDM Measurement Method





$$\mathbf{H} = -\mu \mathbf{B}\frac{\mathbf{S}}{s} - d\mathbf{E}\frac{\mathbf{S}}{s}$$

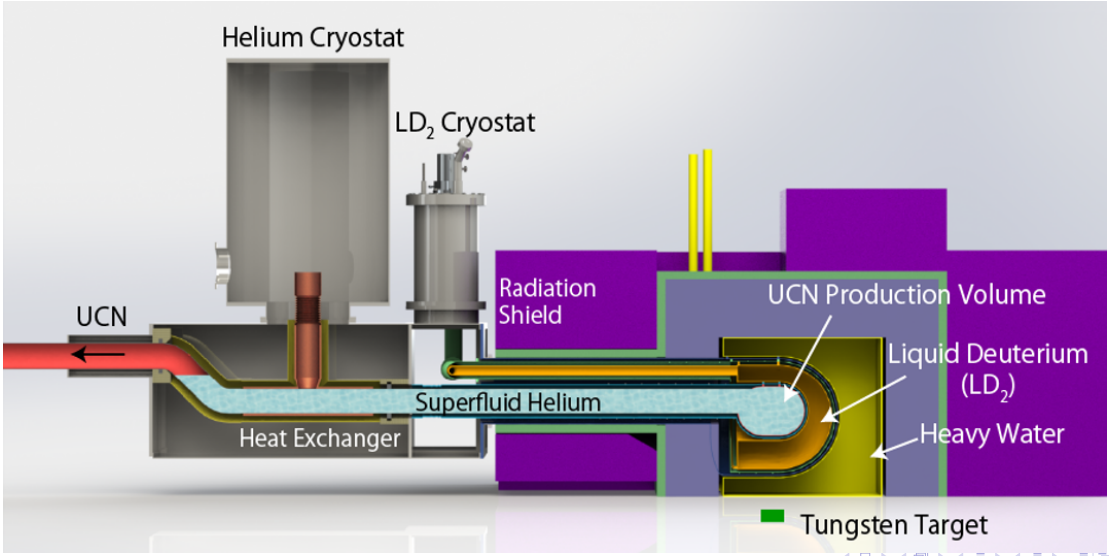
$$\hbar\omega_n^{\uparrow\uparrow} = \mu B + dE$$

$$T\mathbf{H} = -\mu \mathbf{B}\frac{\mathbf{S}}{s} + d\mathbf{E}\frac{\mathbf{S}}{s}$$

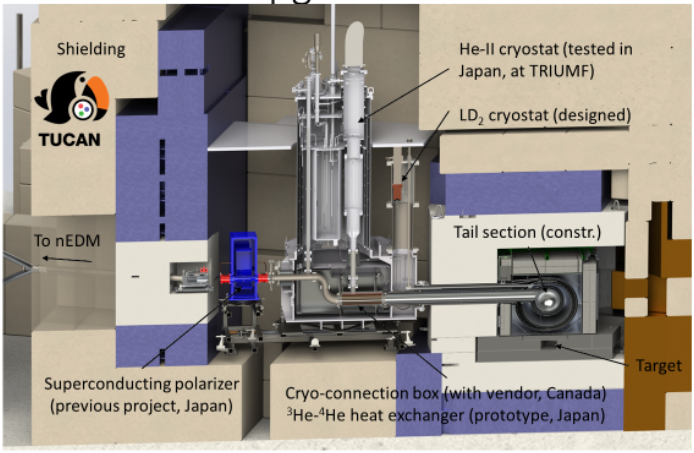
$$\hbar\omega_n^{\uparrow\downarrow} = \mu B - dE$$

$$\hbar\omega_n^{\uparrow\uparrow} - \hbar\omega_n^{\uparrow\downarrow} = 2dE$$

UCN Production Method

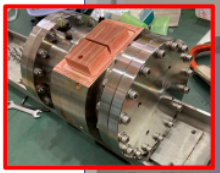


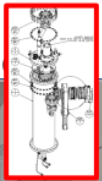
Horizontal source upgrade

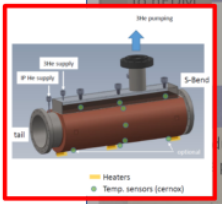


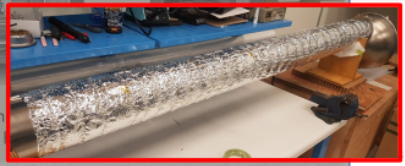
7

Horizontal s…

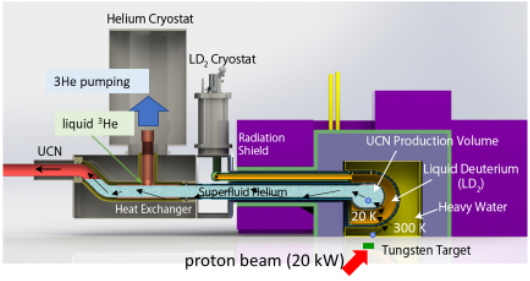






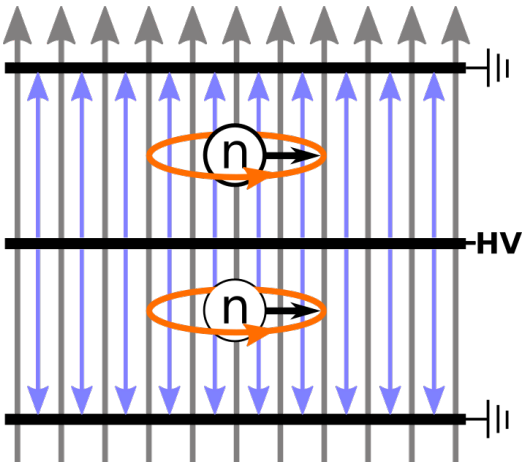


TUCAN Source Upgrade Concept and Goals



- LD_2 moderator
  - increase cold neutron flux at 1 meV ($\times 2.5$)
- Helium Cryostat with high cooling power
  - production volume ($\times 3$)
  - proton beam power ($\times 50$)
    - 0.5 kW -> 20 kW
    - heat load on superfluid : 8.1 W
      - include heat deposit on vessel
  - superfluid helium temperature ($\times 1/3$)
    - $T_{He\text{-}II}$ = 1.2 K (0.8 K@RCNP)
    - Storage lifetime : $\sim$ 30 sec
- Estimated source performance
  - production rate: 1.4 x 10^7 UCN/s
  - UCN density
    - 6×10^3 UCN/cm^3 @ production
    - $\sim$220 UCN/cm^3 @ measurement

Measurement Method Revisited



- This requires a 1 μT holding field that has gradients smaller than 1 nT/m, and is stable to 1 pT over 100 s
- Using double cells also requires the linear gradient between the cells to be less than $10pT/m$ to match the precession frequency between the cells for measurement method.
- Insufficient uniformity will depolarized the neutrons over the measurement cycle, or cause a measurement of a false nEDM.

Sensitivity Estimates

UCN production rate	1.4×10^7 UCN/sec	
UCN loaded into EDM cell	220 pol. UCN/cm^3	14M UCN
UCN detected at end of cycle	23 pol. UCN/cm^3	**1.4M UCN**

S. Sidhu, et al. arXiv:2212.04958 (SSP 2022 conf. proc.)

Compare to typ **15,000 UCN** detected at previous best expt. (ILL/PSI), and **121,000 UCN** projected for n2EDM

N. Ayres, et al., Eur. Phys. J. C 81, 512 (2021)

$$\sigma_d = \frac{\hbar}{2\alpha E t_c \sqrt{N}}$$

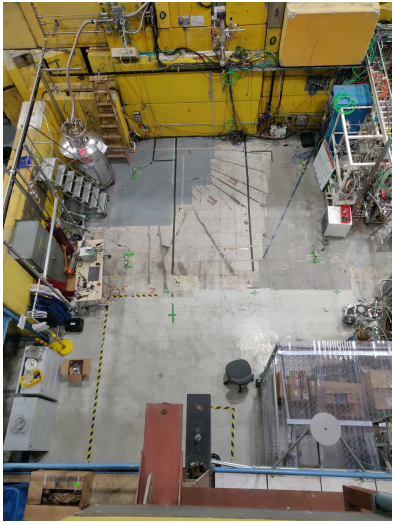
E = 12.5 kV/cm
t_c = 188 s
α = 0.6 (visibility)

σ_d = 2 x 10^{-25} *e*cm/cycle

To reach statistical sensitivity of $\sigma_d = 1 \times 10^{-27}$ ecm
400 days of running required

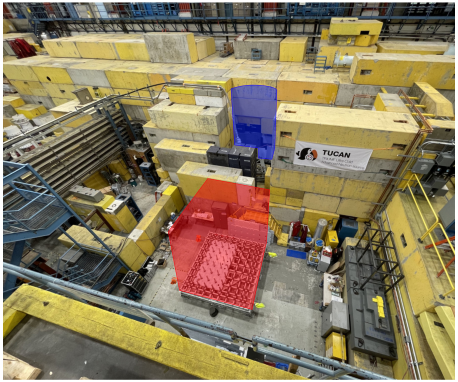
article doi: https://doi.org/10.1051/epjconf/202328201015

Magnetic Environment

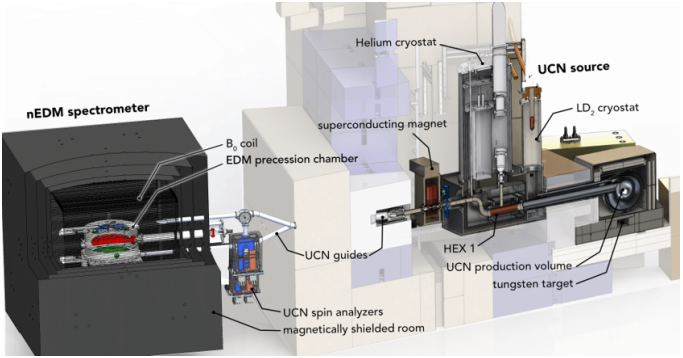


- The proximity to the TRIUMF cyclotron creates an elevated local magnetic field in the hall.
- Hall Field: $\sim 370\,\mu\mathrm{T}$
- Earth Field: $30 - 60\,\mu\mathrm{T}$
- From this ambient field we need to provide a field in the measurement cells that is only $1\,\mu\mathrm{T}$ vertically.

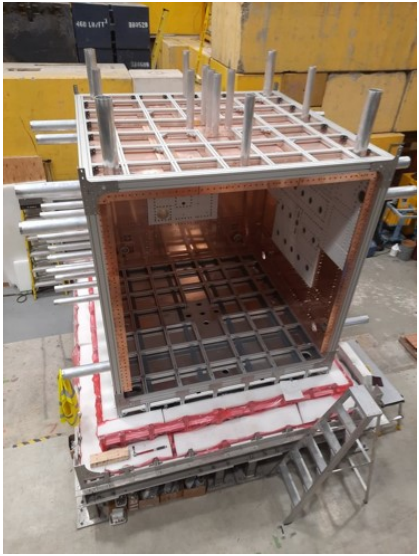
Layout in our area in Meson Hall at TRIUMF

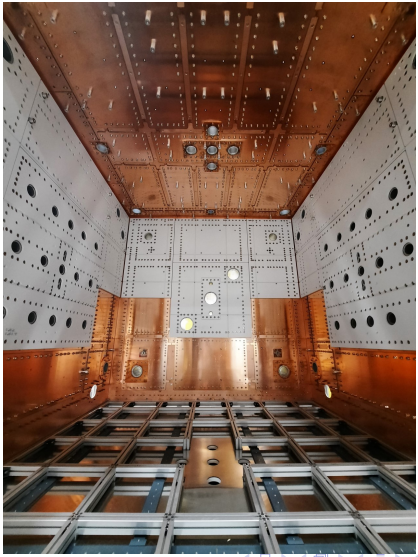


Status fall 2022



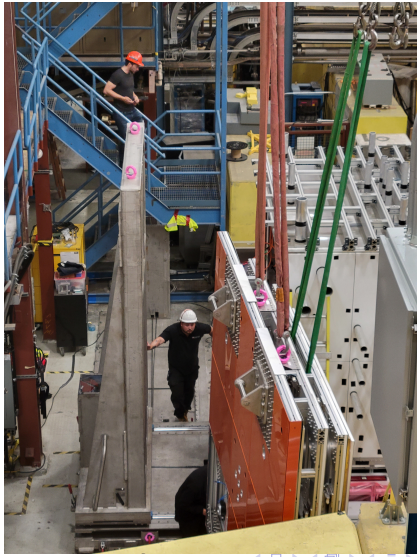
MSR Construction First Layers



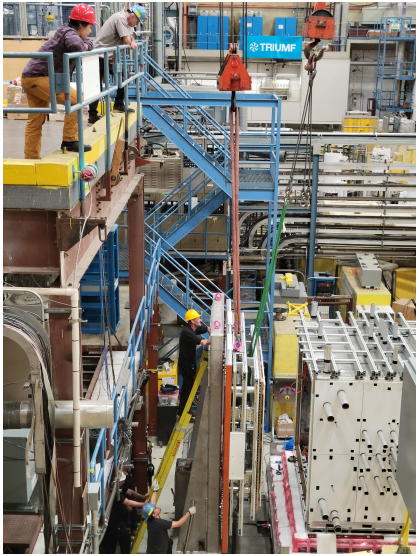


MSR Door Installation

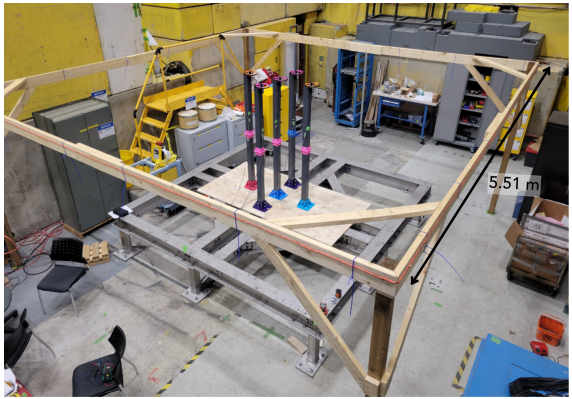
MSR Door Installation



MSR Door Installation



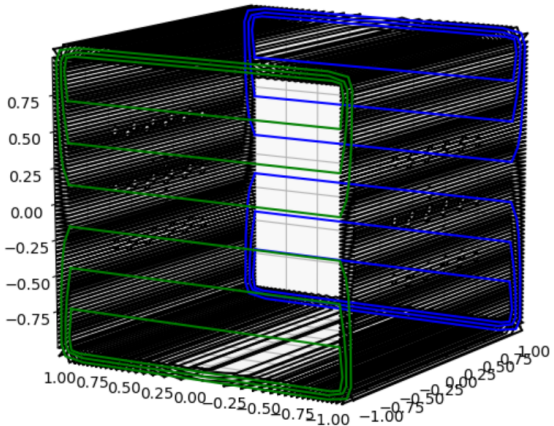
Next Milestone - Shielding Factor Tests



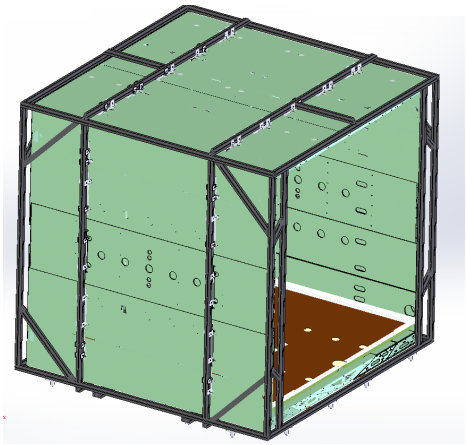
Pre-installation measurement, Sept. 2022

- The shielding factor of a MSR is the factor by which it reduces external magnetic fields.
- Now that the copper layer (and door and floor mu-metal) are installed the first-layer shielding factor measurements for the room are underway this week.

B0 Coil Design

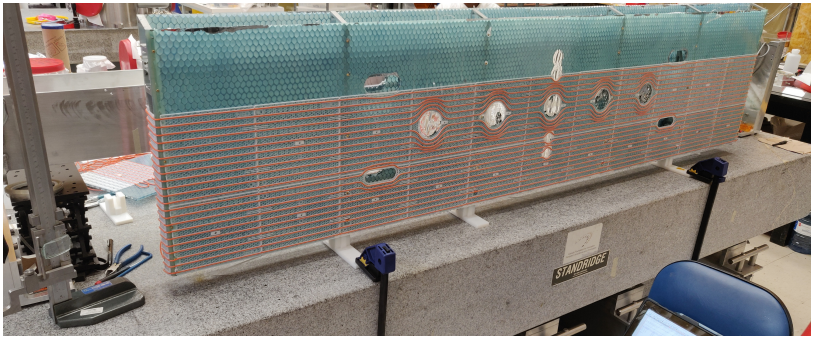


Self-shielded coil design



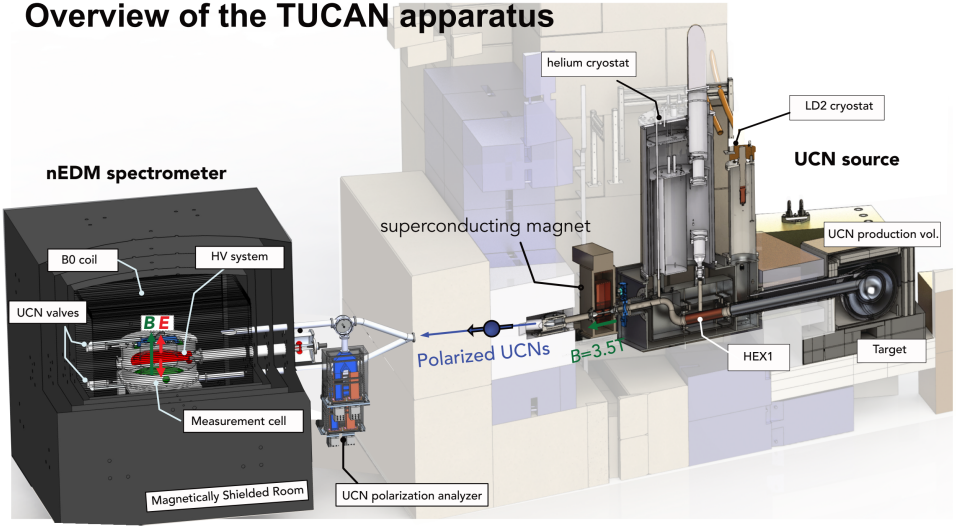
Exo-skeleton coil support

B0 Coil Prototype

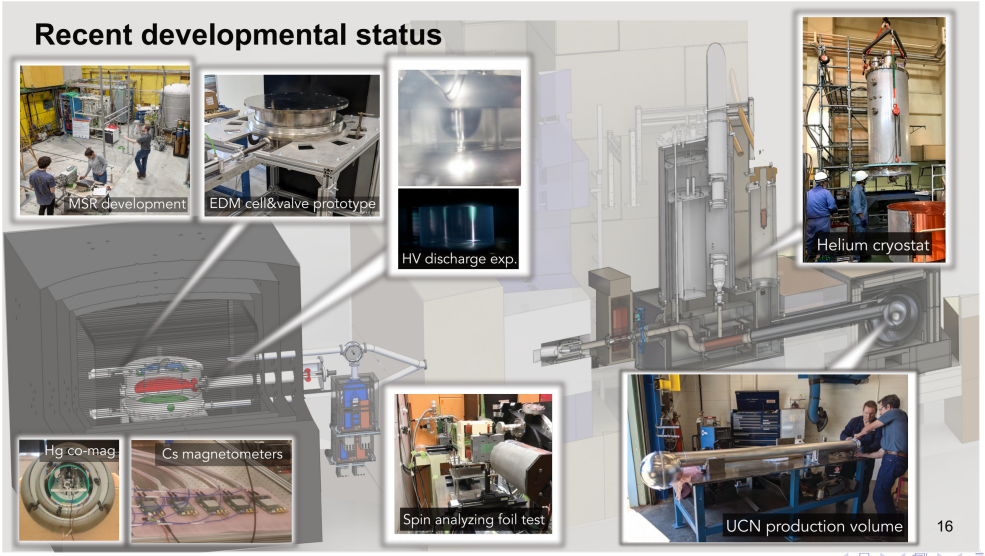


- Assembly of full-sized prototype module and initial winding was completed Friday last week.
- Analysis of measurements and non-contact point map is under way.
- Initial Results show deflections of $1 - 3\,\mathrm{mm}$ from design under its own weight, target was $< 1\,\mathrm{mm}$; will be fixed in final version which uses more robust construction

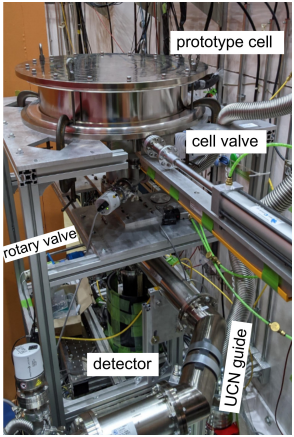
TUCAN Subsystems



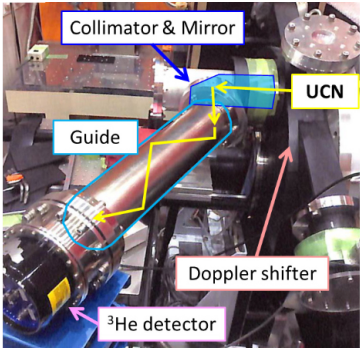
TUCAN Subsystems



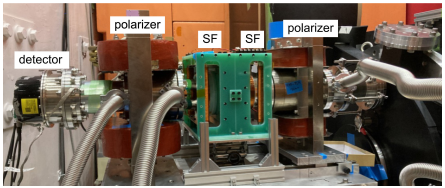
Testing at J-PARC



Cell and Valve



UCN Guide



UCN Polarizer

Images courtesy of Takashi Higuchi

Thank You

The TUCAN Collaboration

Spare Slides

NxN Coils